April 1992
NSRP 0343

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

TECHNICAL PANELS:

SP-1: FACILITIES AND ENVIRONMENTAL EFFECTS
SP-3: SURFACE PREPARATION AND COATING
SP-4: DESIGN/PRODUCTION INTEGRATION
SP-5: HUMAN RESOURCE INNOVATION
SP-6: MARINE INDUSTRY STANDARDS
SP-7: WELDING
SP-8: INDUSTRIAL ENGINEERING
SP-9: EDUCATION

SP-7

FINAL REPORT:

EVALUATION OF HITACHI ZOSEN PORTABLE WELDING ROBOTICS

PROJECT FUNDED BY THE U.S. NAVY

PROJECT PERFORMED BY NEWPORT NEWS SHIPBUILDING

PROJECT MANAGED BY PETERSON BUILDERS. INC. (NSRP LEAD YARD -- INDUSTRIAL PROCESSES)-

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CONTRACT NO. HO0167-90H-O057

INITIAL EVALUATION OF THE HITACHI ZOSEN WR-L50 PORTABLE WELDING ROBOT

A PROJECT OF

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

FOR

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS

SHIP PRODUCTION COMMITTEE

SP-7 WELDING PANEL

PREPARED BY NEWPORT NEWS SHIPBUILDING

G. J. BLASKO, SUPERVISOR, MANUFACTURING ENGINEERING
D. J. MONIAK, WELDING ENGINEER
B. C. HOWSER, CHIEF WELDING ENGINEER

MARCH 1992

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Much of the success of this trip to Japan is due to Mr. Ken Matsuo, Assistant Manager of Hitachi Zosen's Ship Business Department. Ken arranged the plant visits, coordinated travel arrangements in Japan, answered hundreds of our questions, and stayed with us for almost the entire trip.

The authors offer their sincere appreciation to Mr. Kenji Shims of Hitachi Zosen, U.S.A. in New York who arranged our visit to Japan, and to Mr. Kazuo “TK" Okazaki of Daihen Corporation for coordinating the team tour of their factory.

Appreciation and gratitude are also extended to the other management and staffs of the Japanese companies visited for allowing the group into their facilities, for sharing their information, and for all the courtesies provided during the visits.

Finally, we thank SP-7 Panel members Frank Gatto (Puget Sound Naval Shipyard), O. J, Davis (Ingalls Shipbuilding), and the NSRP Program Manager of Industrial Processes, James Rogness (Peterson Builders, Inc.) for providing input into this report.

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1.0 EXECUTIVE SUMMARY

The application of robotics provides good potential to increase welding productivity, reduce dependence on skilled labor, and improve the competitive position of U.S. shipyards. However, shipyard robotic applications have generally been limited to small part sizes and repetitive batch lots.

In June 1991, Newport News Shipbuilding proposed this project and was subsequently awarded a contract from the National Shipbuilding Research Program (NSRP) to complete an initial evaluation of portable welding robots developed by Hitachi Zosen of Japan. The project was completed under the auspices of the NSRP SP-7 Welding Panel.

In December 1991, a team representing U. S. private and public shipyards and the David Taylor Research Center visited three Japanese shipyards to observe the Hitachi Zosen robots in operation and complete a technical assessment.

The portable welding robots are not the conventional teach-playback variety, but rather a numerically controlled (NC) system that utilizes off-line programming. The robots and their robot origin transfer (self traveling) units are compact, durable, easy to operate and are readily adaptable to high-volume, non-repetitious structural welding tasks. The robots offer excellent productivity improvement due to their potential for 50-70% arc time, high deposition rates, and ease of operation and set-up. Typically, three robots were being operated by a single operator.

Hitachi Zosen has clearly expressed an interest in selling the portable welding robots to U.S. shipyards. However, their concerns regarding third-party product liability and potential patent infringement issues will have to be closely monitored.

There are several issues that a U.S. shipyard will have to resolve to ensure a successful implementation including determining the availability of the special Nippon flux-cored weld wire in the U. S., assessing weld quality in terms of U.S. regulatory requirements, and customizing the CAM software to suit specific design details.

Based on the team's observation and the overall satisfactory technical assessment, it is recommended that at least one portable welding robot with a transfer unit be purchased for further evaluation in a U.S. shipyard.

2.0 BACKGROUND

To improve the competitive position of U.S. shipyards, increased welding productivity at reduced cost must be promoted. Robotic welding provides the potential to increase welding performance but has not yet proven effective for processing very large, non-repetitive parts in the United States. Shipyard applications have generally been limited to small part sizes and repetitive batch lots. The use of a portable robotic welder could expand the potential applications to include large structural hull assemblies.

Newport News Shipbuilding has monitored advances in Japanese shipbuilding technology, particularly robotic welding, for the past decade. On a visit to Japan in December 1982, Dick Pruden and Ben Howser of NNS and other members of the SP-7 Panel were made aware of the initial development of the Hitachi Zosen portable robot. At that time, the design concept was under way but hardware development had not yet started.

In mid-1990, Newport News Shipbuilding became aware of a significant leap in automated welding technology with the commercial introduction of a programmable, portable welding robot developed by Hitachi Zosen's Ariake Works. Our initial assessment was that Hitachi Zosen had developed a robotic approach that was particularly innovative and offered excellent potential for welding productivity improvements.

This assessment was confirmed in September 1990 when these robots were observed in operation at the Lindoe Shipyard in Denmark. The robots were impressive in their ease of set-up, operation, and programming. Productivity gains were evident since a single operator was running three robots simultaneously with minimal intervention. As far as we can determine, the Lindoe Shipyard is the only shipyard outside of Japan that is using the Hitachi Zosen portable welding robot.

Because of potential value to the U.S. shipbuilding industry, Newport News Shipbuilding submitted a proposal for the evaluation of the portable welding robot to the SP-7 Welding Panel for consideration. The project concept was approved and Newport News Shipbuilding was awarded a contract to complete an initial technical evaluation. The primary technical objectives of this project were:

- o To observe the operational capabilities of the Hitachi Zosen portable welding robot in a shipbuilding production environment.
- o To determine potential benefits in fabrication, productivity, quality and welding performance utilizing Hitachi Zosen portable welding robots.
- o To evaluate the interface between the CAD and CAM systems and the ability of the Hitachi Zosen equipment to interface with other shipyards' computer design systems.

3.0 APPROACH

A team traveled to Japan in December 1991 to visit Hitachi Zosen's Ariake Works as well as any other Japanese shipyards that were using the portable welding robot.

Newport News Shipbuilding representatives participating in the trip were:

G. J. Blasko, Supervisor, Manufacturing Engineering
D. J. Moniak, Welding Engineer
B. C. Howser, Chief Welding Engineer and SP-7 Panel member

The following SP-7 Panel members were also in attendance:

J. Rogness, Peterson Builders, Inc., SP-7 Program Manager
O. J. Davis, Ingalls Shipbuilding
F. Gatto, Puget Sound Naval Shipyard
D. P. Rome, David Taylor Research Center

The following summarizes the itinerary and highlights of the trip:

Hitachi Zosen Ariake Works

On December 2, and 3, 1991, the team visited Hitachi Zosen's Ariake Works in Omuta, Japan. This yard, built in 1973, is Hitachi's largest and most modem with a capacity of six VLCC'S per year. Because of government-imposed constraints on capacity, the yard is only building four VLCC'S per year. The yard employs approximately 1,200 people of which 400 are subcontractors.

The visit included a tour of Ariake Work's structural fabrication and assembly shops, final assembly areas, and dry docks. The portable welding robots were observed under actual production conditions. The team was provided technical presentations on the development, design, programming and operation of the robot as well as an overview presentation of their robotic welding plans for the future.

Robotic welding currently accounts for **20%** of their welding and their short-term goal is to achieve 50%. Their long-term goal is that 80% of all structural welding will be accomplished with robots and 95% of all welding will be accomplished in the flat or horizontal position. Eighty-five percent of all shipyard structural welds and 100% of all robot welds are made using a specially formulated seamless flux-cored electrode (FCAW).

Robots are used predominantly for making straight line welds. Three-dimensional accuracy control is considered absolutely critical for robotic welding. Ship structure component parts are expected to be located within plus or minus 1 millimeter. Self-propelled and twin torch gantry mounted robots were used for fillet welding stiffeners.

When stiffener heights did not interfere, welds were made on both sides of a stiffener at the sometime. In 1992, the shipyard panel line is expected to make extensive use of robotics and will be operated completely by unskilled labor.

Robots were observed welding fillet welds through a pre-construction primer (20 ± 2 microns thickness) on one or sometimes both structural members. The primer is intended to only last one month. It was noted that slower welding speeds and weaving were required while welding through the primer. Vertical welds by the robot are completed with one pass vertical-down to seal the joint and the second pass vertical-up in order to obtain the proper size weld. There was no interbead cleaning unless the weld required more than three welding layers.

Because of a shortage of workers, Japan has established a goal to replace one-third of its work force with robots. Through the use of robots and other automated processes, Japan has increased the yearly electrode consumption per welder per year from 1.0 ton in 1980 to 5.8 tons in 1990.

Daihen Corporation

On December 5, 1991, the team visited Daihen Corporation, formerly known as Osaka Transformer Company. This plant manufactures robots, laser welding and cutting systems and has a welding school on site to train and certify welders for other Japanese companies. Daihen Corporation is a supplier of robots and welding equipment to Miller Electric in the United States.

The plant was impressive in that 200 robots per month are assembled and tested by 14 people. Their streamlined production operation made extensive use of Statistical Process Control (SPC) and Just-In-Time techniques. Daihen Corporation received the Deming Award in 1987.

Hitachi Zosen Maizuru Works

On December 6, 1991, the team made a brief visit at Hitachi Zosen’s Maizuru Works near Osaka. This yard has about 70 years of experience constructing both commercial ships for the world market and surface vessels for the Japanese Navy. Maizuru also manufactures and sells automated systems for welding structural beam and column connection assemblies for the construction of buildings.

Our visit included a tour of the shops that assemble the robotic welding systems for structural assemblies. The twin torch gantry system and the extended reach robot system used by the Ariake Works are assembled at Maizuru Works.

The team also toured the dry dock area where we observed construction of a double hull VLCC using the recently developed unidirectional hull design.

Sumitomo Heavy Industries (SHII) Oppama Shipyard

On December 9, 1991, the team visited SHI's shipyard in Oppama. This yard was built in 1971 and has a peak capacity of six VLCC's per year. The yard is currently building 95,000 DWT tankers and 140,000 DWT bulk carriers.

Our visit included an extensive tour of their structural fabrication and assembly shops and their dry dock area. We were also provided an overview of their robotic welding applications including:

- A robotic assembly line for setting and fitting stiffeners to plate.
- Single and double torch gantry systems for welding stiffeners to shell plate.
- A track-mounted articulated robot for welding stiffeners on smaller assemblies.
- Eight Hitachi Zosen portable robots with robot origin transfer units to weld the primary (egg-box) structure of the hull.
- A series of ten track-mounted robots for welding the underside stiffeners of large block sections of the ship.
- Four fixed-position robots for welding small and medium sized pipe flanges.

Overall, SHI utilizes **25** robots at this plant with plans to install an additional 25 robots. SHI estimates that their total investment in robotics is about 4 million U.S. dollars.

4.0 PERSPECTIVE ON **HITACHI ZOSEN CONSTRUCTION PHILOSOPHY**

While this report provides a technical evaluation of the Hitachi Zosen portable welding robot, we believe the readers must gain an appreciation of its development and how it fits into the overall construction philosophy of the shipyard.

There is a hidden danger in selectively "picking and choosing" individual elements of Japanese shipbuilding technology to be used in U.S. shipyards. In the case of the portable welding robot, the danger lies in the all-too-typical approach of purchasing automated equipment (islands of automation) but not integrating that equipment with the ship design and construction process planning effort.

The portable welding robot should not be viewed as the end product of years of research and development, but rather as a significant pre-planned and achieved milestone in the design of long-range ship construction improvements. At Ariake Works, these improvements have focused on streamlining production processes and increasing the volume of work completed at the earliest stages of construction. The focus in welding has obviously been in developing assembly processes that complete as much welding indoors in the flat position as possible. Work is designed and grouped according to its shape and joint type to achieve the highest percentage of automatic welding. New ship designs incorporate and take advantage of the full range of robotic capabilities by considering weld size, length, position, space restrictions, etc.

In the words of Tatsuo Miyazaki, Manager of Production Technology Development and Chief Welding Engineer at the Ariake Works, "Automation is designed considering the integration and omission of activities. Activity is shifted upstream as far as possible, aiming at keeping the activity in a better environment, the expansion of automation and the decrease of handling allowing fine production control. "

Hitachi Zosen has a company-wide philosophy that strives to reduce costs while eliminating dirty, difficult and dangerous work. It was obvious that the portable welding robots were not developed as islands of automation, but rather as pre-planned and designed-in elements of continuous process control and improvement.

Based on our observations at Ariake Works and at Sumitomo Heavy Industries (SHI) Oppama Works, there are several factors that characterize the successful development and application of robotic welding technology:

- Ship designs that are developed with a strong consideration of welding processes and joining techniques.
- Ship designs that incorporate well-defined manufacturing processes and process controls including Just-In-Time techniques, detailed planning, and SPC where appropriate.
- An integrated working relationship between design, planning and manufacturing to facilitate process flow and facility utilization.
- Efficiently planned and standardized work to make maximum use of the work force and minimize downtime.
- Long range plans for construction process improvements including the expanded use of CADCAM systems and standard designs to facilitate manufacturing automation such as robotic welding, cutting, plate marking and painting.
- Management involvement and commitment to continuous process improvement.
- The development of automation and related technologies that are simple and not "over-kill" for the particular application.

5.0 OVERVIEW OF HITACHI **ZOSEN WR-L50 PORTABLE WELD ROBOT**

The Hitachi Zosen WR-L50 portable robot, shown in Appendix A, Photo 1, is a flexible, automated robotic welding system developed specifically for welding the primary structure of the mid-sections (egg-box structure) of ships at the assembly stage of unit construction. Physical attributes of the robot, including size, work envelope, load capacity and number of axes were chosen based on current and foreseeable ship design criteria.

The robot was designed for ease of handling, minimal operator set-up time and intervention, and for use in small confined spaces where a robot would be beneficial. The robot can be combined with a robot origin (self traveling) transfer unit (Appendix A, Photo 2) that expands the operating range of the robot to include traveling the length of a structural bay between two longitudinal stiffeners. Additional stationary fixtures can be utilized to allow a wider range of robotic welding applications (Appendix A, Photo 3).

The WR-L50 portable welding robot is not a conventional teach-playback robot but rather a numerically controlled (NC) robot that utilizes off-line programming making it particularly adaptable to high-volume, non-repetitious structural welding tasks. The required machine control code is created by manual entry of design information into menu-driven, PC-based software.

Computer output is downloaded via floppy disc or bubble cassette to the robot's controller on the shop flax. After loading the NC data, the robot operator may add, delete, and insert data optionally on the robot's control panel.

Because of its simplicity, one operator can operate three robots simultaneously. Hitachi Zosen states that each robot achieves an average arc-time of 50-70% and can deposit more than 20 kg (44 pounds) of filler metal per eight hour shift.

6.0 TECHNICAL EVALUATION

6.1 Computer Aided Manufacturing (CAM) System

Hitachi Zosen has been successful in developing a simple CAM system for operating the WR-L50 portable welding robot. Although the link between their portable robot CAM system and their Computer Aided Design (CAD) system has not been developed, the robot was found to be easy to "program" through menu-driven software.

In addition to the robot and its controller, the following hardware/software is included in the system:

- a personal computer with a minimum 1 MB RAM, 20 MB hard drive, 3.5” floppy disc drive

- monochrome or color monitor

- 15” printer

- Robot NC data generation software

Robot NC Data Generation System

The robot data generation software provides a menu-driven system for a planner to describe and input the geometry of a section of the ship’s structure. Principal features of the software include:

- pre-programmed fundamental hull structure geometry that depicts the basic configuration of ship’s structure (skin plating with two longitudinal frames and two transverse bulkheads)

- a pre-programmed list of variables for the fundamental hull structure such as type of longitudinal stiffeners, frame spacing, types of brackets, etc.

- pre-programmed welding variables dependent on single or multi-pass weld and leg lengths

- automatic movement simulation (not displayed) to minimize starts and stops depending on the limitations of the robot movement

- automatic generation of opposite side weld paths

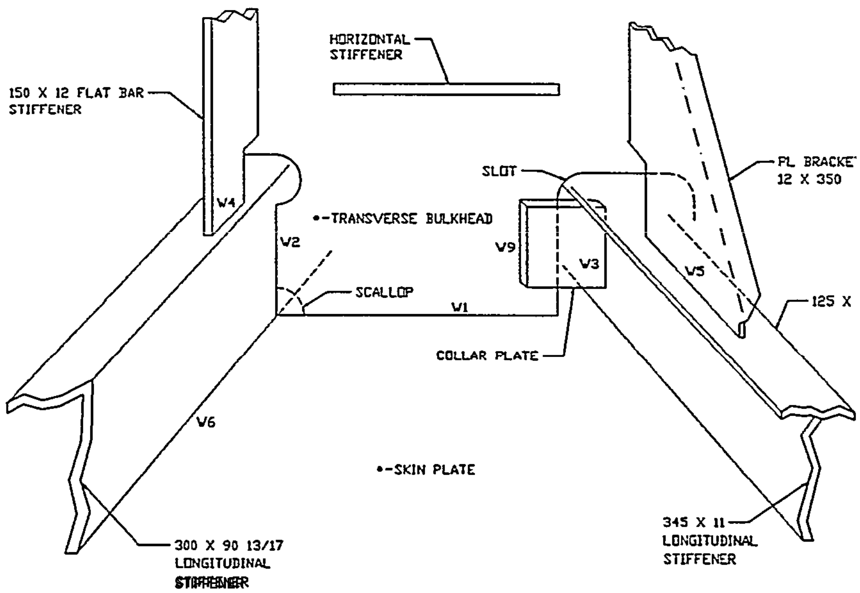
- an interference avoidance check between movement of the robot and ship’s structure

- automatic generation of machine language

Data Entry/''Programming

The team witnessed a demonstration of data input to program a typical portion of a ship's structure. The following summarizes the steps of that operation:

- The planner works with a CAD 3-D sketch (or 2-D drawing if necessary) that depicts the structural area to be programmed. For purposes of our demonstration, the following sketch was used:



- The planner then gains access to the software on the PC and simply enters the geometric description of the space to be welded. The following represents the information entered for our demonstration:

```
WORK NAME          = NSRP/DEMO
SIDE (P/S)         = P
FLOOR ANGLE        = 90.000
FLOOR THICKNESS    = 12.500
LONGL SPACE        = 860
HOR. STIFF HEIGHT  = 0
-------------------LEFT-------RIGHT--
LONGL*FLOOR ANGL  = 90.000  | 90.000
LONGL*SKIN ANGL   = 90.000  | 90.000
LONGL WEB DEPTH   = 300.000 | 345.000
LONGL WEB THICK   = 13.000  | 11.000
LONGL FACE BREAD  = 90.000  | 125.000
LONGL FACE THICK  = 17.000  | 20.000
LONGL NIGE        = L       | L
LONGL MUKI        = L       | L

STIFF TYPE        = 1       | 1
STIFF*LONGL ANGL  = 90.000  | 90.000
STIFF*FLOOR ANGL    90.000  | 90.000

STIFF BREADTH     = 150     | 350
STIFF THICKNESS   = 12      | 12
STIFF SHIFT       = 10      | 0
STIFF SCALLOP     = 35      | 50

SLOT TYPE         = A712    |T712
SLOT SCALLOP      =         | 50
COLL. PLATE       =         | 2
COLL. FITTING     =         | 0

WELD TYPE & LEG-----------TYPE - L L---------
   (W 1)      =      6.0
   (W 2)      =      7.0
   (W 3)      =      7.0
   (W 4)      =      5.0
   (W 5)      =      5.0
   (W 6)      =      6.0
   (W 7)      =      0.0
   (W 8)      =      0.0
   (W 9)      =      7.0
   (W10)      =      0.0
   (W11)      =      0.0
   (W12)      =      0.0
   (W13)      =      0.0
   (W14)      =      0.0
   (W15)      =      0.0
   (W16)      =      0.0
```

- Upon completion of data entry, the software runs the movement simulation and interference avoidance check and then develops the machine language code for the robot's controller.

Structural Data Input

Appendix B provides a summary of the dimensions, fitting angles, and overall capabilities of the welding robot. Appendices C and D summarize the types of slots and collars programmed into the software and their weld limitations.

Structural Data Output

The generated NC data is transferred via floppy disc to the robot's controller when the structural welding is to be completed. A hard copy is provided as a record of the structure data input.

An additional unique output is a summary of the projected elapsed time for completing the actual welding operation. Included are summary calculations of elapsed weld time and footage, elapsed time and number of robot moves, and elapsed time and quantity of sensing operations.

Assessment of CAM System

Based on the demonstration provided by Hitachi Zosen, programming the robot appears to be relatively easy and straight-forward. Working from CAD 3-D sketches (or 2-D drawings if necessary), a "planner" should quickly become proficient at entering the required design input. Because of the repetitive nature of the ship's structure within each block/unit, data entry costs should be minimal.

Direct input from a CAD database would be an enhancement and is technically feasible. However, the lack of this interface is not a significant drawback. This link can be a natural evolution once a shipyard has a significant quantity of robots in operation.

The robot's software is designed to work with metric dimensioning while U.S. designs are typically based on feet and inches. This should not be a significant problem since most CAD systems can easily convert between the two.

Hitachi Zosen is willing to modify the software to accommodate design details specific to another shipyard.

6.2 Operating the Robot

To start production welding, the operator lowers the robot onto the structural assembly using a dedicated overhead bridge crane. Because of its relatively small physical size and weight, the operator can easily slide the robot into position. Placement of the robot within the structure is not critical; however, there is a target location near the weld start point for initial alignment.

A job identification number links the CAM generated data to the egg-box structure to be welded. The operator inputs the identification number into the teach pendant which downloads all required machine control data to the robot.

When coupled with the robot origin transfer unit, the robot uses ultrasonic sensors to determine its distance from the transverse frame, and infrared sensors to determine its distance from the longitudinal stiffeners. This feedback is compared to the CAM design data which had determined the zone required to complete the welds. The robot will then guide itself to the necessary location and begin the welding operation.

After the welds joining the skin plate to the transverse bulkheads are completed, the robot completes the horizontal fillet welds joining the skin plate to the longitudinal frames. Because of the closeness of the longitudinal frames on the application we observed, the robot was unable to turn itself around to complete the welds at the other end of the egg-box structure. In this case, the robot was lifted using a crane and turned around to complete the welding.

6.3 Equipment

Power supply cables, shielding gas lines, and control cables are conveniently supplied by an overhead bridge crane. This crane also is used to move the robot from location to location within the sub-assembly. (Appendix A, Photo 4)

As observed, wire feeders are attached to the robot origin transfer unit with approximately three feet of conduit between the torch and wire feeder drive rolls.

The 1.2mm diameter electrode is supplied in spools weighing approximately 30 lbs. One hundred percent carbon dioxide shielding gas is utilized. The electrode drive mechanism is of the single roll type with a wire straightener. To increase accessibility of the torch, the contact tip was extended approximately 3/4” from the gas cup. Detailed specifications for the robot and origin transfer unit are provided in Appendix E.

6.4 Weld Tracking

Once positioned inside the structure, touch sensing is used to determine the actual location of the beginning and end of each weld. Depending on the weld’s accessibility, each start or stop location is found using either two or three search patterns. Prior to each search, approximately two inches of electrode is extended from the contact tip to serve as the touch sensing surface. A wire straightener is used to reduce the electrode deflection as it exits the contact tip and increase the accuracy of the search.

The touch sensing system utilizes a 400 volt charge applied to the welding electrode and was observed sensing through primer-coated steel plate. Our experience with a 42 volt based touch sensing system has revealed difficulty sensing through mill scale and paint on ship parts.

Through-the-arc seam tracking is used to track the joint after welding has started. This tracking method is only applied on longer length welds such as the horizontal fillet weld joining the longitudinal stiffeners to skin plate. Mechanical contact sensors are utilized to prevent the robot from backing into the transverse bulkhead at the other end of the work bay.

6.5 Weld Sequence and Fillet Weld Sizes

The sequence of welding is established during the CAM movement simulation. This feature optimizes the order in which the welds are completed and reduces both the number of weld starts and stops and the overall distance the robot must travel.

Horizontal fillet welds are completed using one pass with a weave. Vertical fillet welds are completed using two passes: a non-weaving, downhand weld is completed first to seal any gap that may exist in the fit-up; an uphand weld is then made using a weave to obtain the desired fillet weld size. When using the downhand technique, root gaps of up to 3mm can effectively be sealed. Root gaps in excess of 3mm result in unacceptable weld quality.

Multiple pass welds of up to three passes are Possible; however, through-the-arc seam tracking is limited to only the first pass. Seam tracking of the remaining passes is not possible due to the lack of a side wall to track. The robot operator was observed making slight adjustments to correct the stickout length during a vertical weld.

The welds we observed were approximately 5/16 inch vertical and horizontal fillet welds. As illustrated in the following table, weld schedules containing the welding parameters and weaving conditions for vertical and horizontal fillet welds have been developed:

Fillet Size	Position	
	Flat	Vertical
4 mm	O	X
5 mm	O	O
6 mm	O	O
7 mm	O	O
8 mm	O	O
9 mm	O	O
10 mm	X	O

Fillet weld sizes using single-pass technique.

Note:
1) **O indicates that welding conditions have already been developed.**
2) **X indicates that welding conditions need to be developed.**
3) **Vertical welding includes the seal weld using the down-hand technique.**

Fillet Size	Number of Passes
9 mm	2
10 mm	2
11 mm	2
12 mm	3
13 mm	3
14 mm	3

Fillet weld sizes using multi-pass technique.

The task of creating this database was simplified by limiting the welding process selection to just the FCAW process and a single wire diameter.

6.6 Flux Core Electrode Development

In 1981, Ariake Works reviewed the welding processes and consumables they used to determine how they could increase production through process optimization. At that time, 60% of the welding was completed with the shielded metal are welding process with semi-automatic gas metal arc welding (GMAW) comprising only 20 %. With the intent to substantially increase the application of automation and robotics, they pursued the FCAW process for several reasons:

o Of the GMAW processes, FCAW has the highest deposition rate for a given amperage.

o FCAW was found to produce the most stable feedability of any consumable. This is an important requirement when using robotic seam tracking.

o. With the introduction of a seamless FCAW consumable, extremely low diffusible hydrogen values are obtainable.

In a joint venture with Nippon Steel, Ariake Works developed a flux-cored consumable and carbon dioxide shielding gas combination specially formulated to weld through primer-coated surfaces. This electrode was too soft and feedability problems were excessive. Working with Nippon Steel, Ariake Works was successful in developing a manufacturing process that increased the hardness of the consumables and eliminated the feedability problems. They are still trying to reformulate the consumable to reduce smoke emissions.

With Nippon Steel being the only producer of that particular electrode, arrangements would have to be made either to purchase it from Nippon or consider requesting a United States wire manufacturer to develop an alternate electrode. It is important to note that the fillet weld size database may have to be altered if an alternate welding consumable or process is used with this system.

Overall, weld quality was considered satisfactory. In some cases, however, we observed welds that would have been questionable if inspected to U.S. regulatory standards.

6.7 Training

At Ariake Works, highly-skilled welders are not used as robot operators. This task is restricted to only unskilled individuals who preferably are totally unfamiliar with welding. This is possible due to the robot's virtual complete control of the welding operation.

Operator training consists of a one-week safety course, a one-week robot operations course, and one week of on-the-job training. At the end of the three weeks, the operator is considered to be capable of operating the equipment in production.

If this system is purchased, three weeks of training for one engineer and one technician is required at Ariake Works to adequately learn the CAM system, robotic operations and maintenance requirements.

6.8 Safety

As with any automated robotic system, safety to the human operator is a major concern. Many of the safety concerns have been reduced by limiting the power output of the robot and the origin transfer unit. The drive motors of the origin transfer unit have a power output of 80 watts each, thus posing minimal danger to the operator.

Each robot operator has access to an emergency stop button located on the teach pendant. Visual indication of the robot's operational status is provided by a system of four colored lights located on the transfer unit of each robot.

Safety issues pertaining to U.S. shipyards must be addressed to identify any requirements that would hinder the system's flexibility.

6.9 Maintenance

Ariake Works reported that the robots have been very durable and that only routine maintenance has been necessary. One robot has been in a production atmosphere since 1985 with no mechanical failure. Standard maintenance is performed quarterly on the second shift so as not to interfere with production. One reason for this durability record may lie in the use of off-line programming coupled with the collision avoidance feature. A major source of wear on a conventional teach-playback robotic system results from collisions between the robot and the work piece during programming.

6.10 Planned Future WR-L50 Applications

At the time of our visit to Ariake Works, a gantry system consisting of one WR-L50 robot and a three-axis gantry placer was under development for the next step of their subassembly stage (Appendix A, Photo 5). Initial implementation of the system will rely on simple CAM data generated on a PC. Depending on the progress of the application software, a gantry system utilizing four WR-L50's on one gantry placer will be integrated to allow welding of more complex subassemblies (Appendix F). Tremendous flexibility will be gained when the robotic cell is linked to the CADCAM system allowing the welding of non-repetitious pieces. The CADCAM linkage will also allow one of the four robots to fail and have its job completed by the remaining three.

7.0 HITACHI ZOSEN ISSUES

To date, the Lindoe shipyard in Denmark is the only shipyard outside of Japan to purchase the portable welding robot. The sale of those robots was part of a larger business agreement that included the license of Hitachi Zosen's CAD software and agreements for steel purchases from Japanese steel mills.

Although Hitachi Zosen is clearly interested in selling their robots to U.S. shipyards, they have expressed two concerns:

- o The first concern involves the issue of third party product liability in the United States. They were clearly concerned about their potential legal liability in the event their robots would be used in constructing a ship that failed for any reason. They cited the legal disputes surrounding the Exxon Valdez as an example.

- o The second concern regards patent protection. The issue here is that there may already be patents or patent applications for similar equipment in the United States.

Hitachi Zosen is seeking legal advice on these issues to determine its potential legal liabilities.

8.0 **RECOMMENDATIONS**

Based on our observation of the portable welding robots in a production environment and the satisfactory results of our technical review, we believe the Hitachi Zosen portable welding robots offer excellent potential to reduce structural welding costs and increase overall productivity. The relative ease of programming provides a wide variety of potential applications for both commercial and naval shipbuilding in the United States.

There are several issues that a U. S. shipyard will have to resolve to ensure a successful implementation of the Hitachi Zosen portable welding robot:

- o Hitachi Zosen's progress in resolving third person product liability and patent protection rights will have to be closely monitored.

- o Specific design details will have to be reviewed with Hitachi Zosen to determine if changes in the robot software are required.

- o Metric dimensioning will have to be provided to input the required geometric data.

- o The availability of the flux-cored weld wire horn Nippon Steel in the United States will have to be determined. An alternate source or consumable may have to be developed, resulting in modifications to the weld schedule database.

- o Safety issues related to a mobile robot must be addressed.

- o Procedure qualifications permitting downhand welding will need to be developed if the evaluation is to be performed on a military or commercial ship.

- o Process controls will be required for fabrication and fit-up to meet the tolerances of the robot.

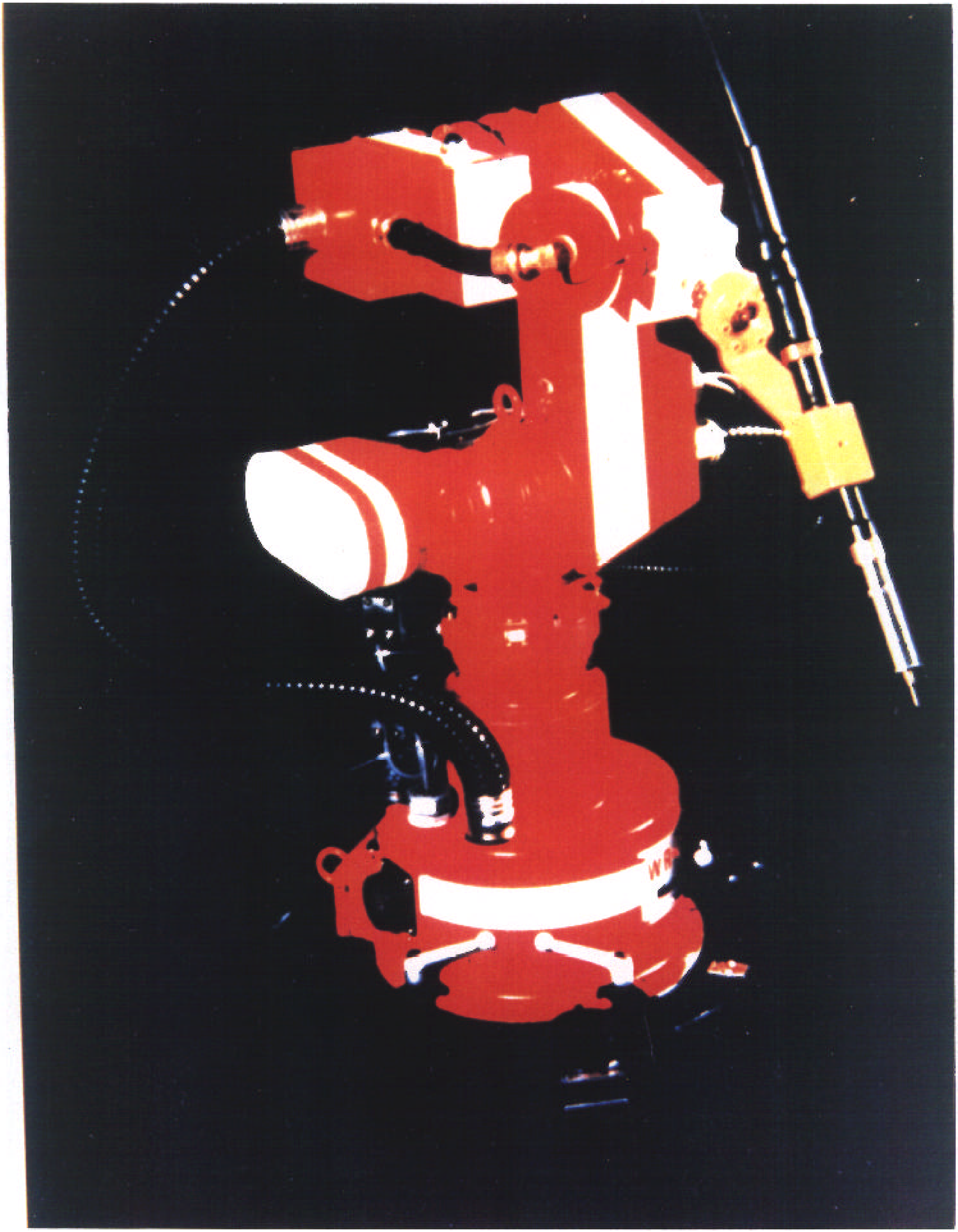
- o Overall weld quality, particularly vertical welds, will have to be assessed in terms of U. S. regulatory requirements.

- o The effectiveness of the touch sensing system on paint and mill scale in a U. S. shipyard will have to be determined.

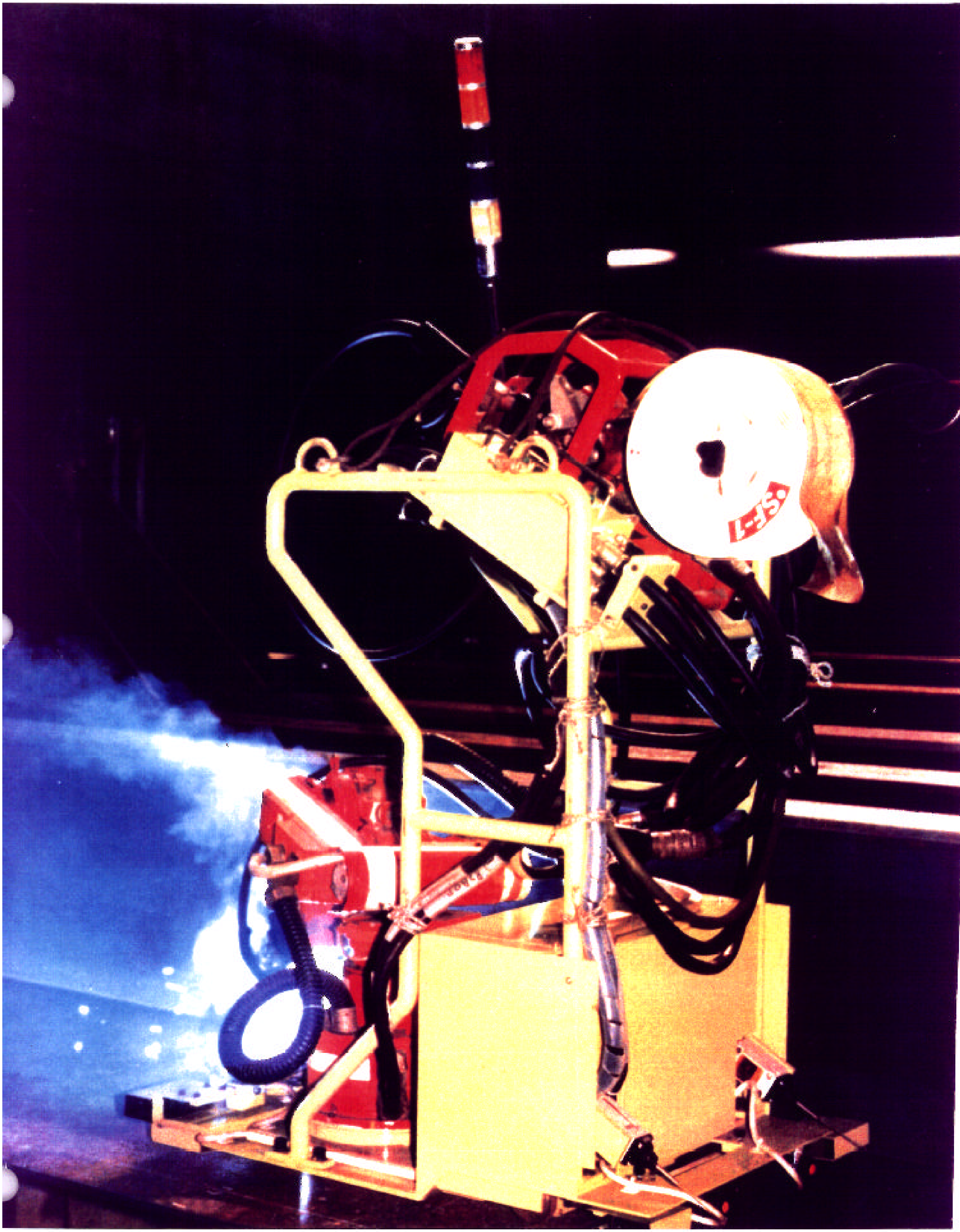
We believe the above issues can be successfully resolved and recommend that the NSRP fund the purchase of at least one Hitachi Zosen portable robot with the robot origin transfer unit for further evaluation by a U.S. shipyard.

APPENDIX A - PHOTOGRAPHS

1. WR-L50 Portable Welding Robot
2. Portable Welding Robot with Origin Transfer Unit
3. Portable Welding Robot on Fixtures
4. Portable Welding Robots Suspended from Overhead Bridge Crane
5. Gantry-Mounted Welding Robot

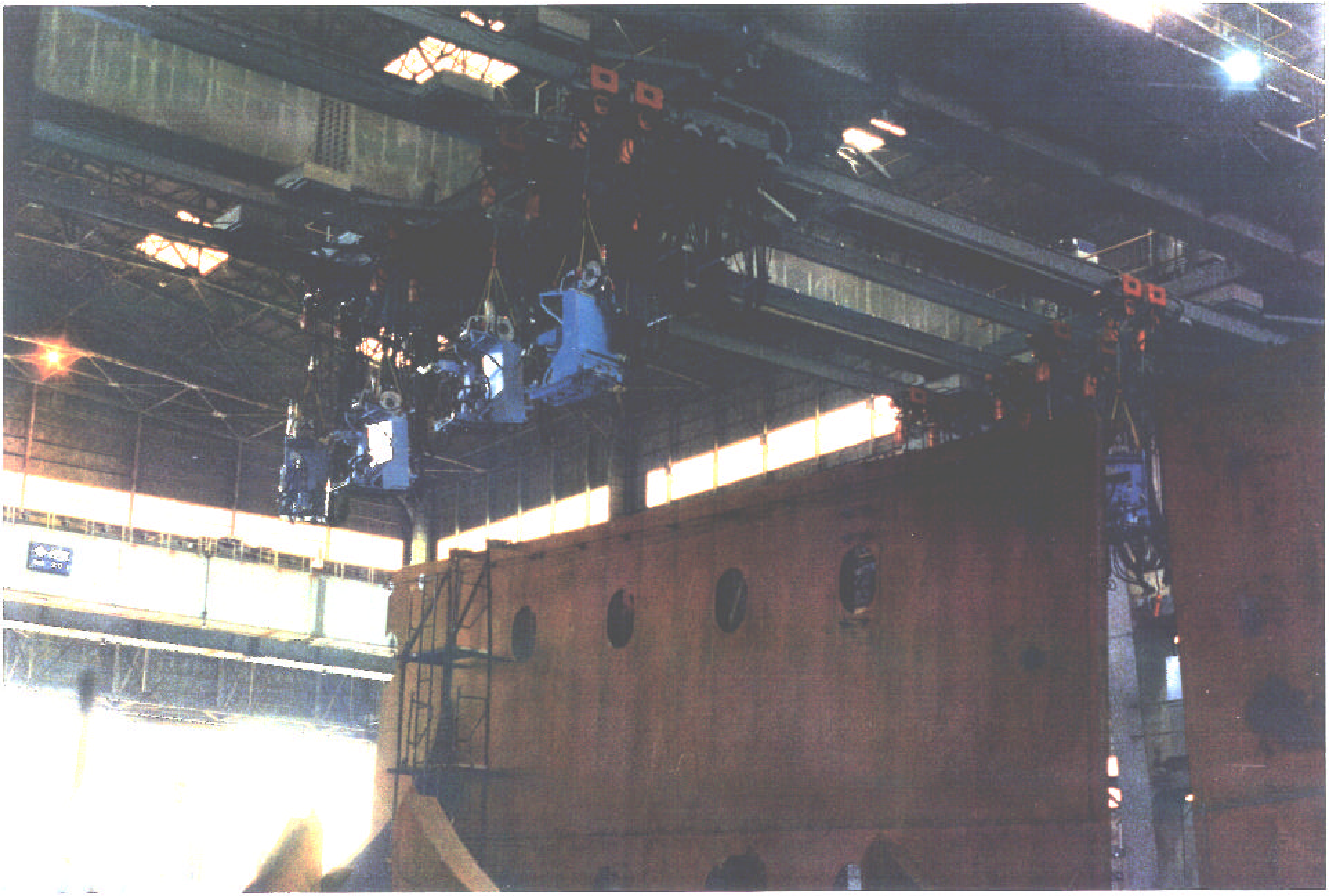


Appendix A, Photo 1
Hitachi Zosen WR-L50 Portable Robot

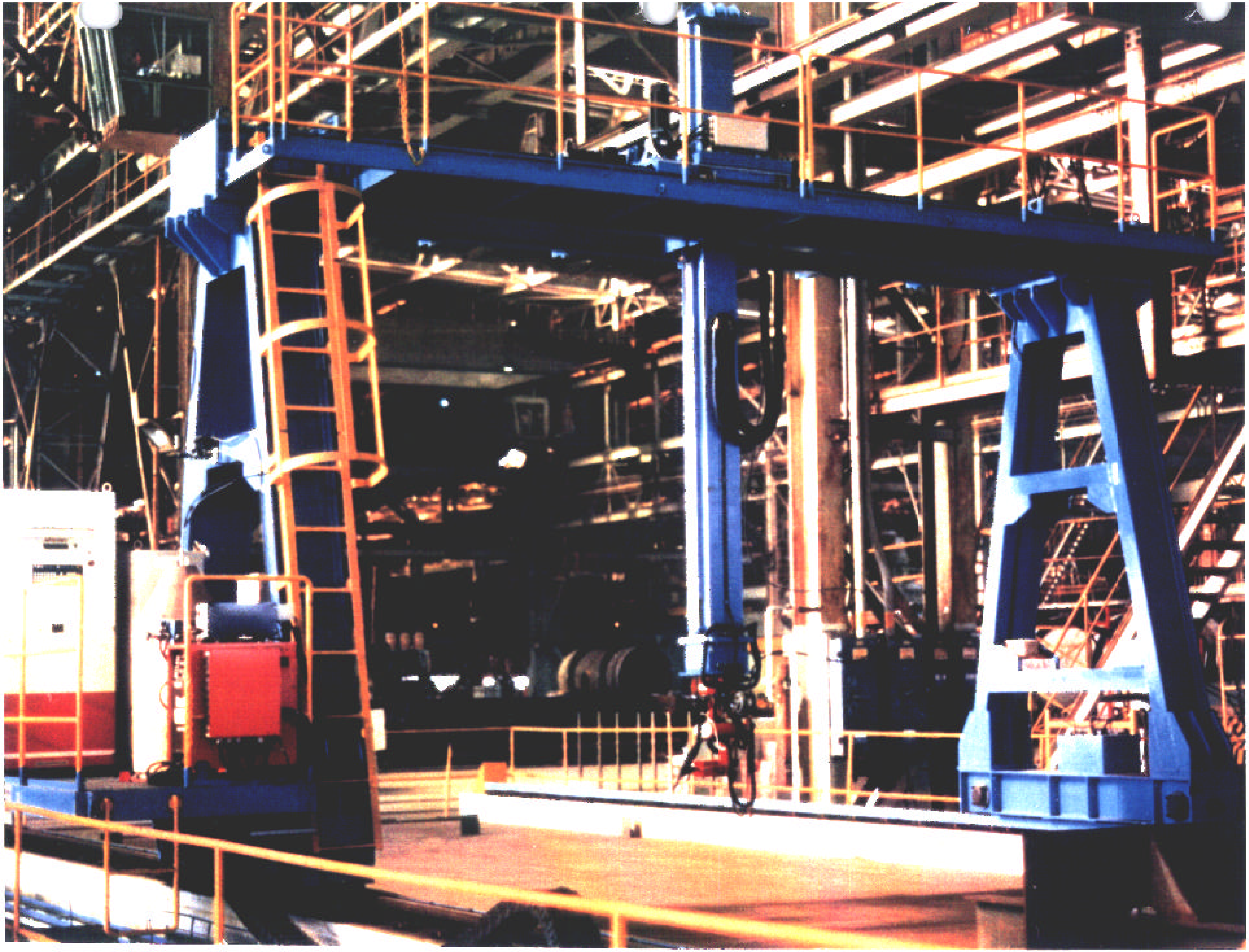


Appendix A, Photo 2
WR-L50 Robot with Robot Origin (Self Traveling) Transfer Unit

Appendix A, Photo 3
WR-L50 Portable Robot with Stationary Fixtures



Appendix A, Photo 4
WR-L50 Portable Robots Suspended from Bridge Crane



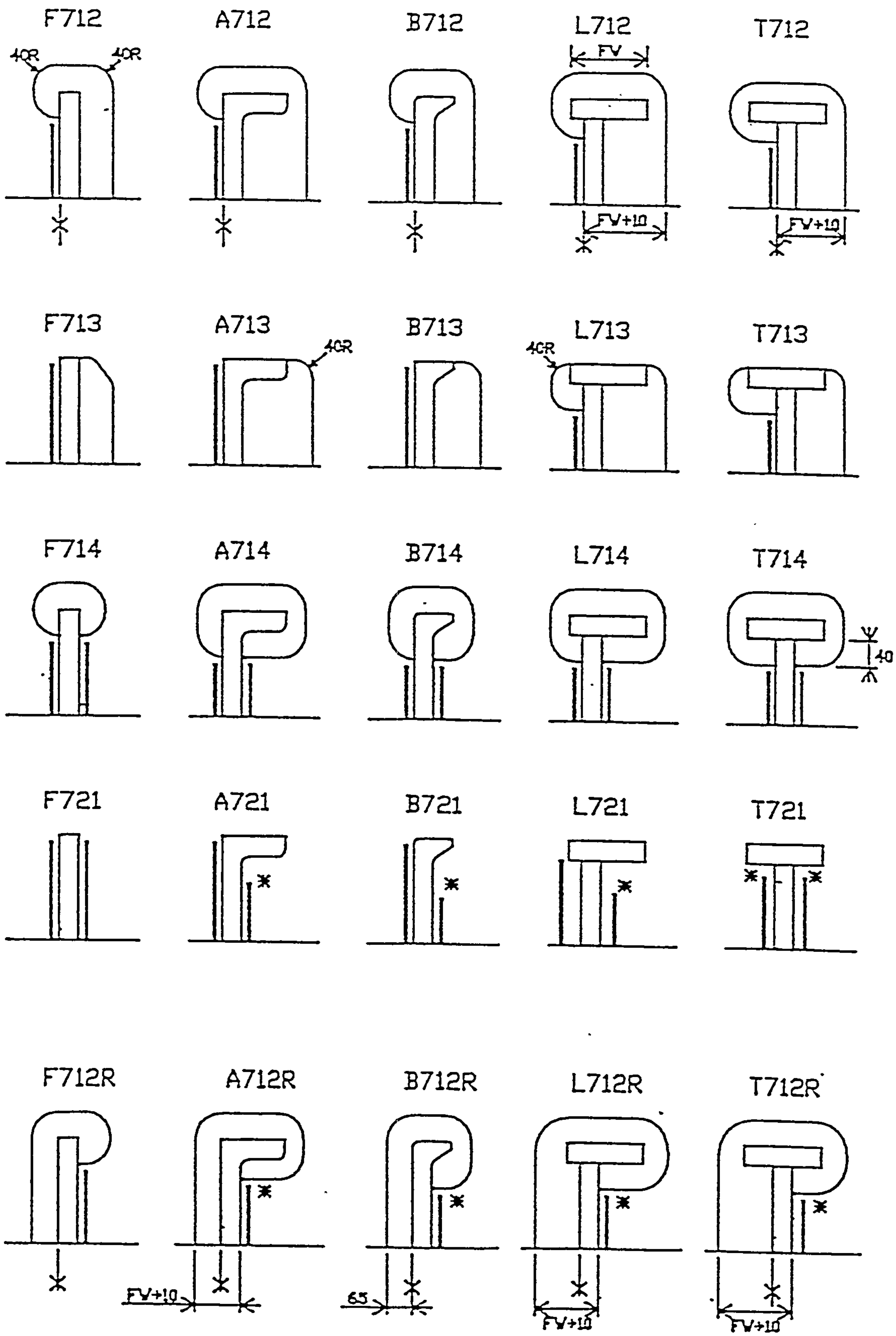
Appendix A, Photo 5
Three Axis Gantry with WR-L50 Robot

APPENDIX B

Input Item	Tolerance of application soft	Tolerance of welding
1 Work Name	Max. 32 Letters	Max. 32 Letters
2 Side (P/S)	P or S	P or S
3 Floor Angle	$60° \leq \Theta \leq 120°$	$90° \pm 5°$
4 Floor Thickness	$6 \leq t \leq 50$	$6 \leq t \leq 50$
5 Longitudinal Space	$500 \leq L \leq 1050$	$500 \leq L \leq$ within the limitation of robot movement
6 Horizontal Stiffener Height	$450 \leq H$	$450 \leq H$
7 Longitudinal ‡ Floor Angle	$50° \leq \Theta \leq 130°$	$90° \pm 5°$
8 Longitudinal ‡ Skin Angle	$50° \leq \Theta \leq 130°$	$90° \pm 5°$
9 Longitudinal Web Depth	$150 \leq D \leq 700$	$200 \leq D \leq 700$
10 Longitudinal Web Thickness	$6 \leq t \leq 50$	$6 \leq t \leq 50$
11 Longitudinal Face Breadth	$0 \leq B \leq 300$	$0 \leq B \leq 300$
12 Longitudinal Face Thickness	$0 \leq t \leq 50$	$0 \leq t \leq 50$
13 Longitudinal Web Nige	L, R, or Δ(space)	L, R, or Δ(space)
14 Longitudinal Face Muki	L, R, or Δ(space)	L, R, or Δ(space)
15 Stiffener Type	1:FB, 2:I∧, 3:BK, or Δ(space)	1:FB, 2I∧, 3:BK, or Δ(space)
16 Stiffener ‡ Longitudinal Angle	$45° \leq \Theta \leq 135°$	$90° \pm 5°$
17 Stiffener ‡ Floor Angle	$45° \leq \Theta \leq 135°$	$90° \pm 5°$
18 Stiffener Breadth	$150 \leq B \leq 750$	$150 \leq B \leq 750$
19 Stiffener Thickness	$6 \leq t \leq 30$	$6 \leq t \leq 30$
20 Stiffener Shift	$-30 \leq S \leq 30$	$-30 \leq S \leq 30$
21 Stiffener Scallop	$0 \leq R \leq 100$	$0 \leq R \leq 100$
22 Slot Type	712, 712R, 713, 714 & 721 or Δ for F, A, B, L, T Type	712, 712R, 713, 714, & 721 or Δ for F, A, B, L, T Type
23 Slot Scallop	R or B ‡ H, Δ	R or B ‡ H, Δ
24 Collar Plate	1 - 4, or Δ	1 - 4, or Δ
25 Collar Fitting	0: Defined face, 1: Opposite face, or Δ	0: Defined face, 1: Opposite face, or Δ
26 Weld Type	L: Single bevel groove, weld T: Multi-pass weld, or Δ	Δ, or T (but T is applicable to the part of floor ‡ skin plate)
27 Leg Length	$4 \leq LL \leq 13$, or 0	$4 \leq LL \leq 13$, or 0 (but 0: no welding, T: $9 \leq LL \leq 19$)

APPENDIX C

Weld access limitations for each programmed slot type.



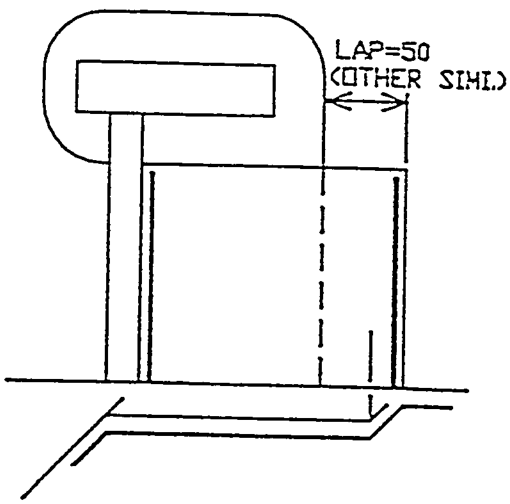
For plates marked with a *, robot geometry limitations can limit the length of the weld.

APPENDIX D

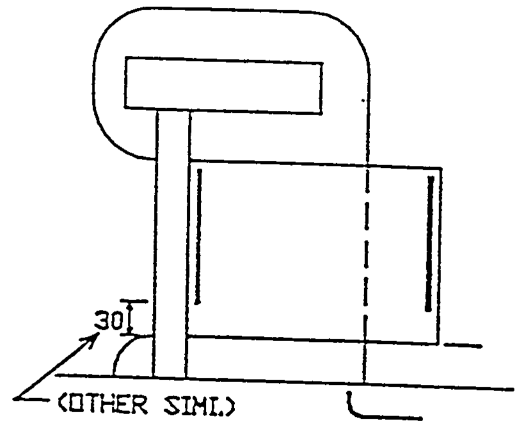
Weld Limitations for each programmed collar plate type.

1. For plates marked with a △, collar geometry and plate thickness can limit the length of weld.

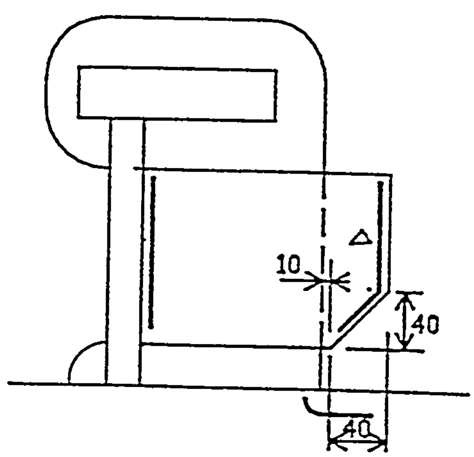
TYPE 1



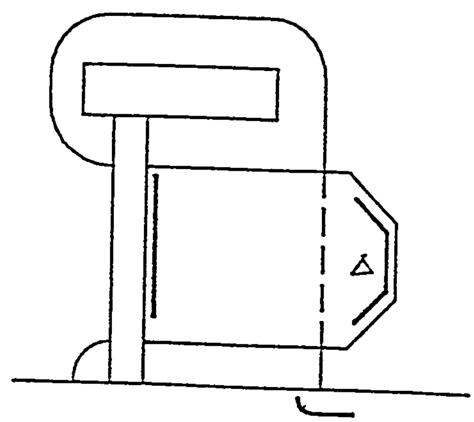
TYPE 2



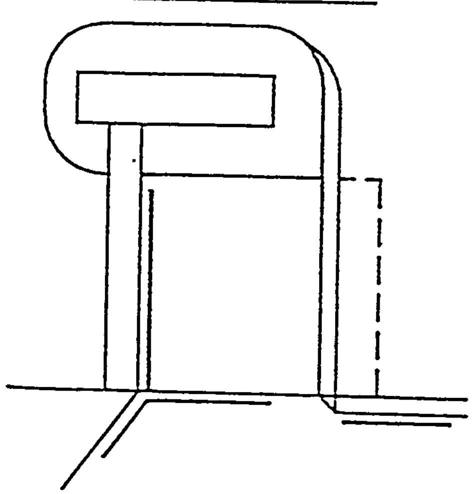
TYPE 3



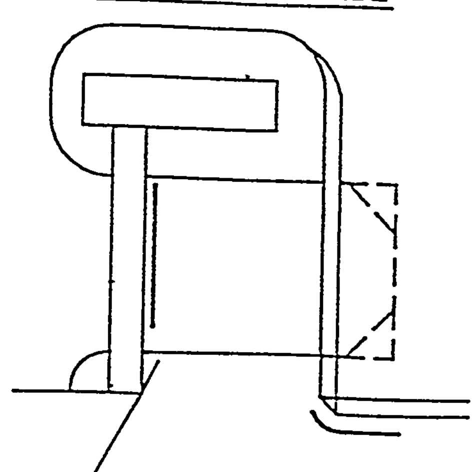
TYPE 4



TYPE 1 BACK SIDE



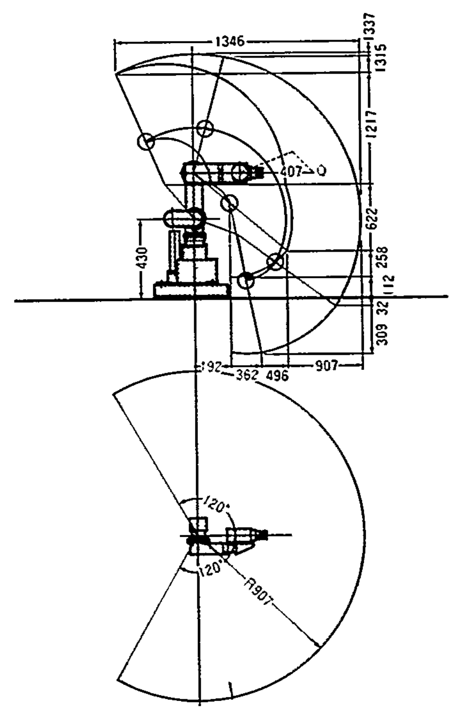
TYPE 2,3,4 BACK SIDE



APPENDIX E

TYPE			WR-L130	WR-L90	WR-L50
ROBOT BODY	DEGREES OF MOTION		5	6	5
	WORKING RANGE (Max. Speed)	WRIST BEND(B3)	230°(140°/S)	220°(70°/S)	240°(60°/S)
		WRIST TWIST(T)	360°(140°/S)	360°(40°/S)	360°(90°/S)
		WRIST ROTATION (θ)	—	180°(100°/S)	—
		UPPER ARM(B2)	110°(45°/S)	135°(85°/S)	135°(60°/S)
		LOWER ARM(B1)	130°(45°/S)	150°(45°/S)	180°(60°/S)
		ROTATION(R)	300°(115°/S)	360°(60°/S)	300°(60°/S)
	HANDLING CAPACITY		MAX. 5 kg INCL.GRIPPER		
	REPEATABILITY		±0.2mm		
	DRIVE		D.C.SERVO MOTOR		
	WEIGHT		APPROX. 250kg	APPROX. 125kg	APPROX. 25kg
CONTROL UNIT	TEACHING METHOD		USING ROBOT LANGUAGE DIRECT BY TEACHING BOX		
	PATH CONTROL		CP PLAYBACK BY PTP TEACHING LINEAR/CIRCULAR		
	SPEED CONTROL		LINEAR VELOCITY CONSTANT CONTROL AT TOOL POINT		
	COORDINATE		ABSOLUTE X,Y,Z AND TOOL ANGLE A,B,C		
	POSITION SENSOR		INCREMENTAL ROTARY ENCODER		
	WORK SENSING		WIRE TOUCH SENSOR AND ARC SENSOR		
	WEAVING FUNCTION		SOFTWARE SYSTEM		
	SETTING OF WELDING CONDITION		INDIVIDUAL SETTING AUTOMATIC SETTING FACILITY OF WELDING PARAMET		
	PROGRAM LANGUAGE		ROBOT LANGUAGE (Approx.30 Commands)		
	PROGRAM CAPACITY		1,000 STEPS. MAX 30,000 (Optional)		
	MEMORY		IC MEMORY		
	SUB-MEMORY		FLOPPY DISK, BUBBLE MEMORY (Optional)		
	EXTERNAL INPUT/OUTPUT		OUTPUT 16CH, MAX.32 (Optional) INPUT 16CH, MAX 32 (Optional)		
	TIME DELAY		0.1~25.5S IN 0.1S INCREMENTS		
	DISPLAY		LCD, CRT (Optional)		
	DIAGNOSTIC FUNCTION		ERROR AND ALARM CODES AND SELF-DIAGNOSTIC CHECKS ARE INDICATED		
	AMBIENT TEMPERATURE		0~40C		
	POWER SUPPLY		AC 200/220V 5 KVA		
	WEIGHT		APPROX.200kg		

Working range

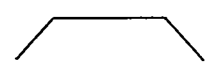


ROBOT SPECIFICATIONS

1. UNIT BODY

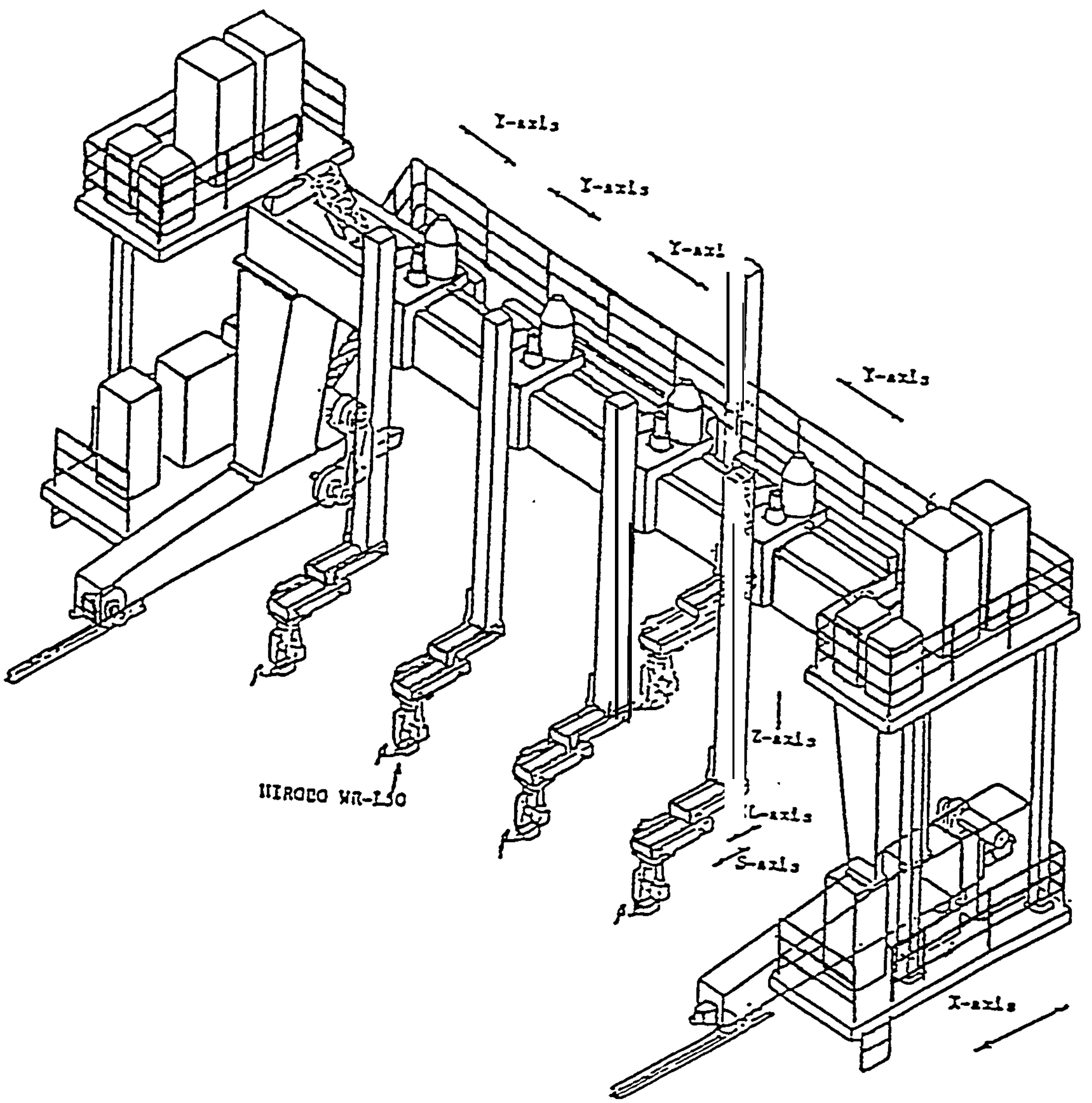
Items	Specification
Construction	Self-driving type with 4 wheels
Ddrive	DC servo motor drive
Steering	Steering by aft wheels
Guidance	Parallel moving by detecting the distance with wall
Controlled axis	4 (Running : 2 Steering : 2)
Running speed	Max. 3.4 m/min.
Steering	Rotation angle : ±180°, Rotation speed : Max. 9.3 r.p.m
Sensor for distance	Type : Non-contact type Direction : 3 directions (Front, Right, Left)
Traction capacity	30kg

2. CONTROL UNIT

Items	Specificatiion
Teaching method	1. Off-line programing 2. MDI input
Path control	CP control by PTP
Position control	Software Servo
Speed control	Constant speed rotation control
Position detector	Pulse Encorder
Number of control axis	Simultaneous 4 axis
Speed setting	Absolute speed setting
Control of acceleration & reduction	
Memory	IC memory (Batt. backup)
Capacity of memory	1,000 Program steps
External memory	Bubble Cassette (128 KB)
External i/0	In, out each 8 points
Indication	LCD (40×2)
Operation mode	HOME, AUTO, STEP, TEACH, PARA
Functions	1. Change of data 2. Alarm 3. Path-Point 4. Linear&Circular Interpolation 5. Sequensor 6. Self-check
Atmospheric temp. & moisture	0-45℃, 45—80% RH
power source	AC 100/110/120 V, 50/60 Hz (±10%)
Constrution	Self standing fully enclosed type

Robot Origin Transfer Unit Specifications

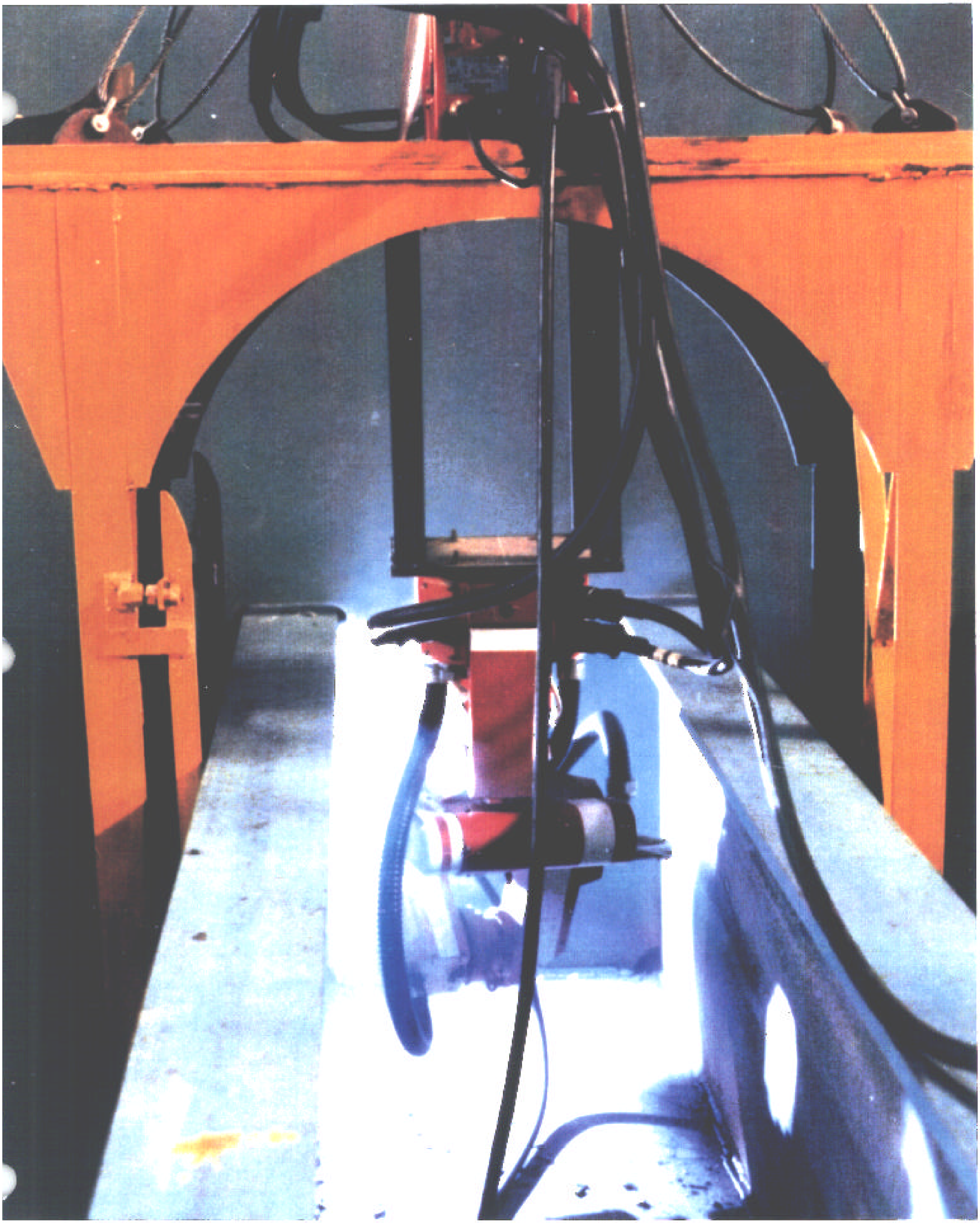
APPENDIX F



Gantry robot mourning plural HIROBO WR-L-50'S
for Unit Block Assembling

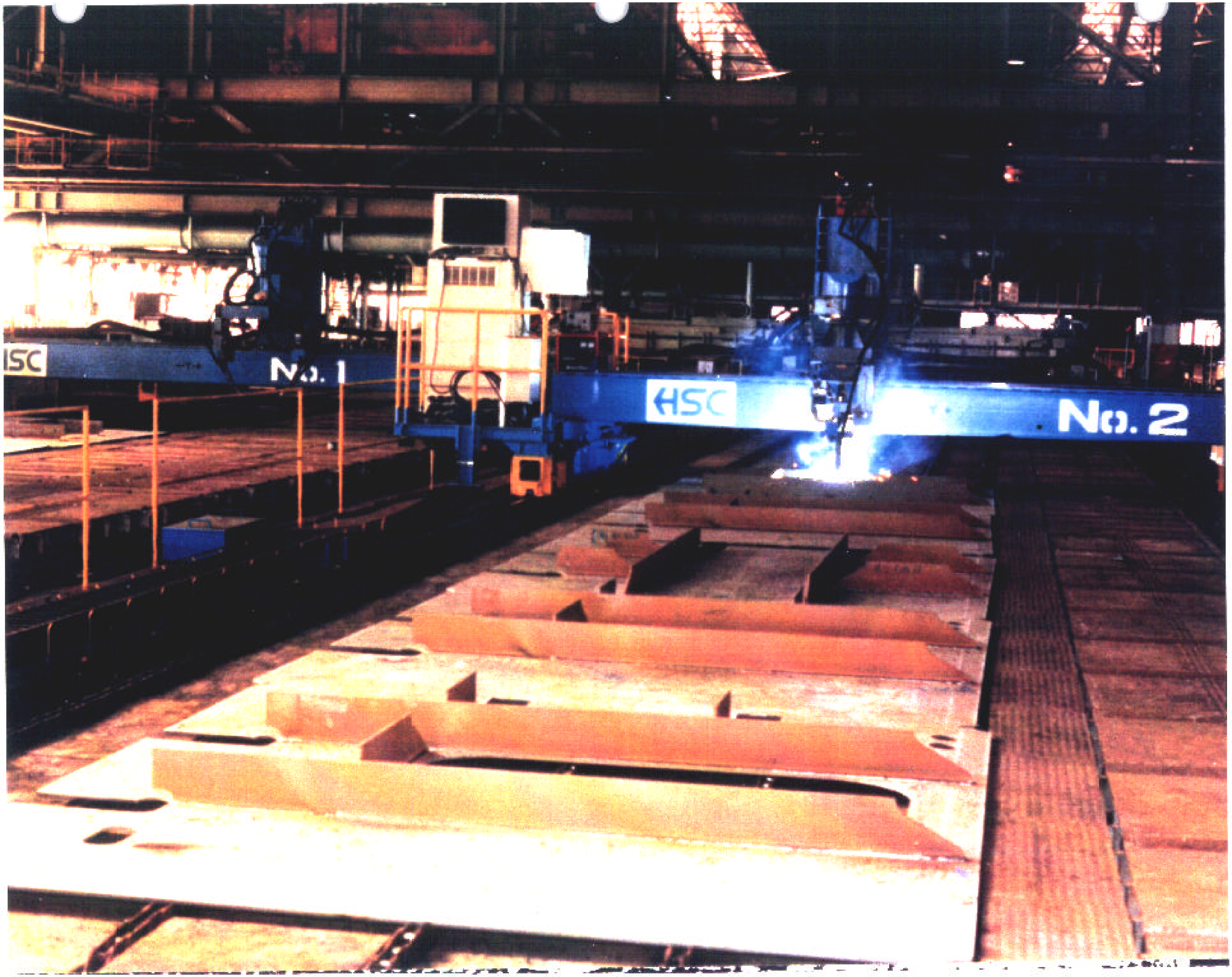
APPENDIX G - SELECTED PHOTOGRAPHS

1. WR-L50 Welding Robot with Stationary Fixture
2. Typical WR-L50 Application at Sumitomo Oppama Shipyard
3. Twin Torch Gantry Robot for Welding Stiffeners at Ariake Works
4. Stiffener Placement Robot at Sumitomo Yard
5. Stiffener Placement Operation
6. Sumitomo's Twin Torch Robot
7. Typical Twin Torch Robot Application
8. Articulated Track Mounted Robot at Surnitomo Yard
9. Touch Sensing in Operation
10. Fillet Welding of Stiffeners to Plate
11. Typical Piece Parts for the Articulated Robot
12. Surnitomo's Robotic Pipe Welding Operation in Progress
13. Small and Medium Pipe Welding Lines
14. Overhead View of Track Mounted Robots Used to Weld the Undersides of Large Sub-assemblies
15. Side View of Track Mounted Robots
16. Bridge Crane Being Constructed to Support Four WR-L50 Deep Reaching Robots for Ariake Works

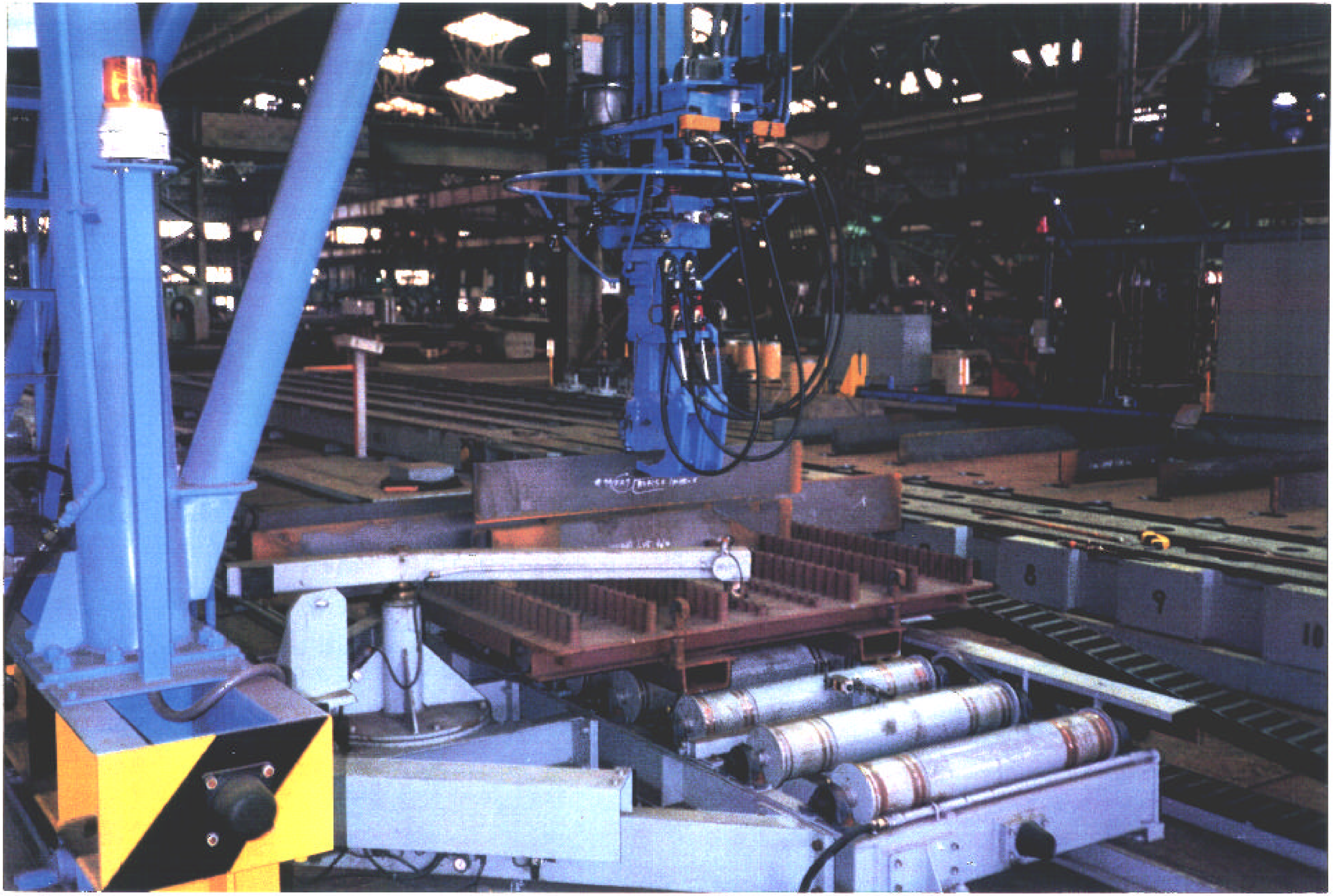


WR-L50 Welding Robot with Stationary Fixture

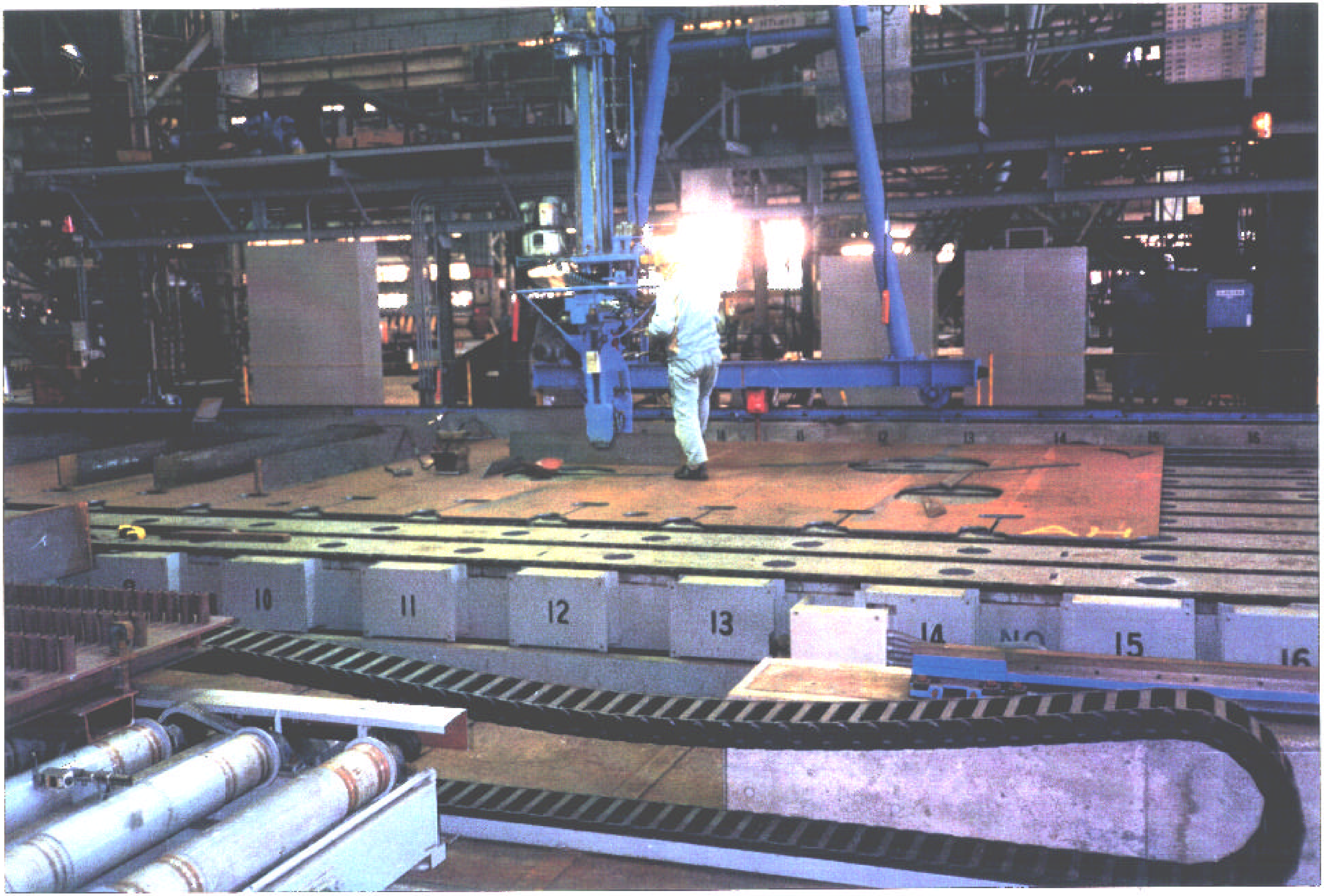
Typical WR-L50 Application   Sumitomo Oppama Shipyard



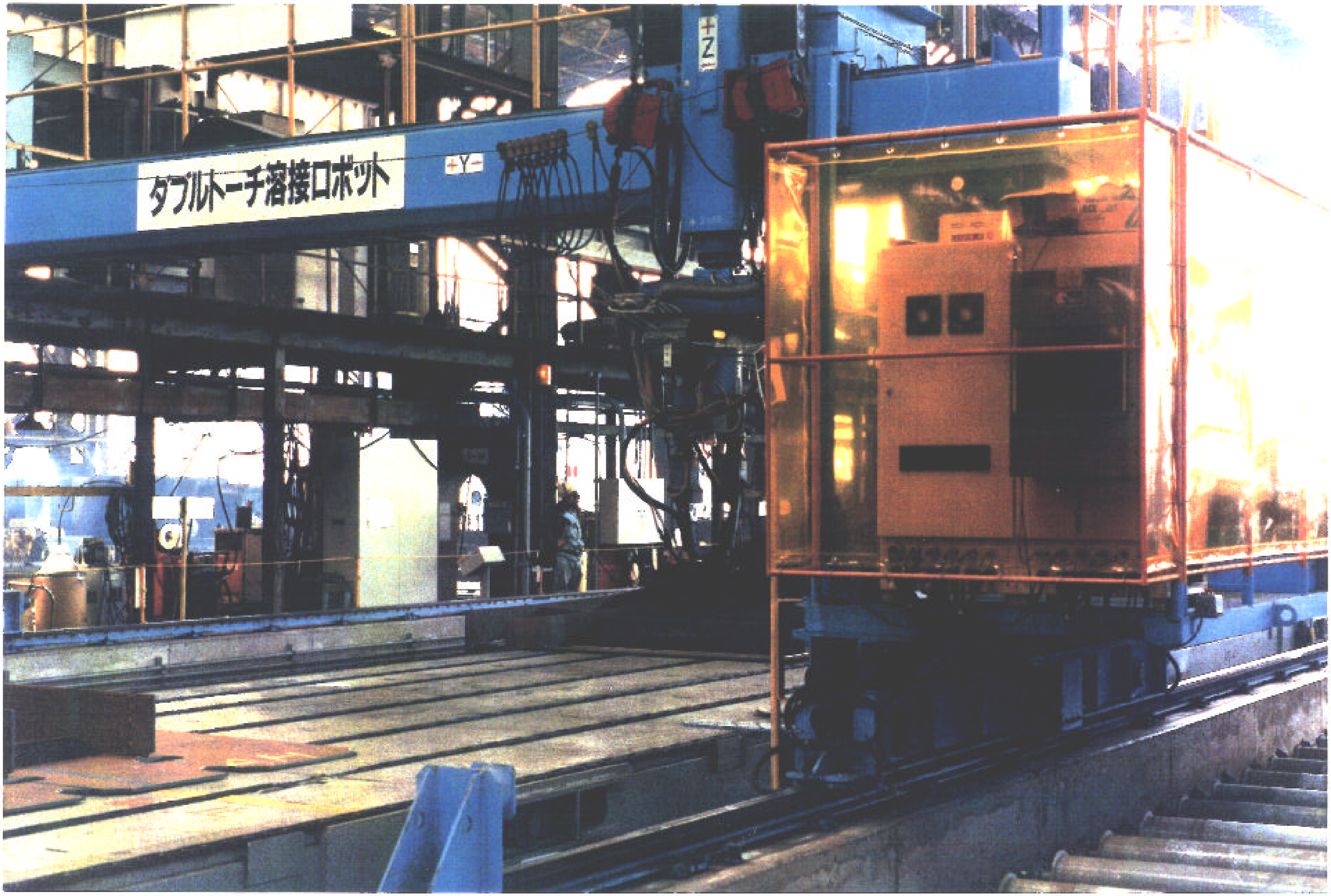
Twin Torch Gantry Robot for Welding Stiffeners at Ariake Works



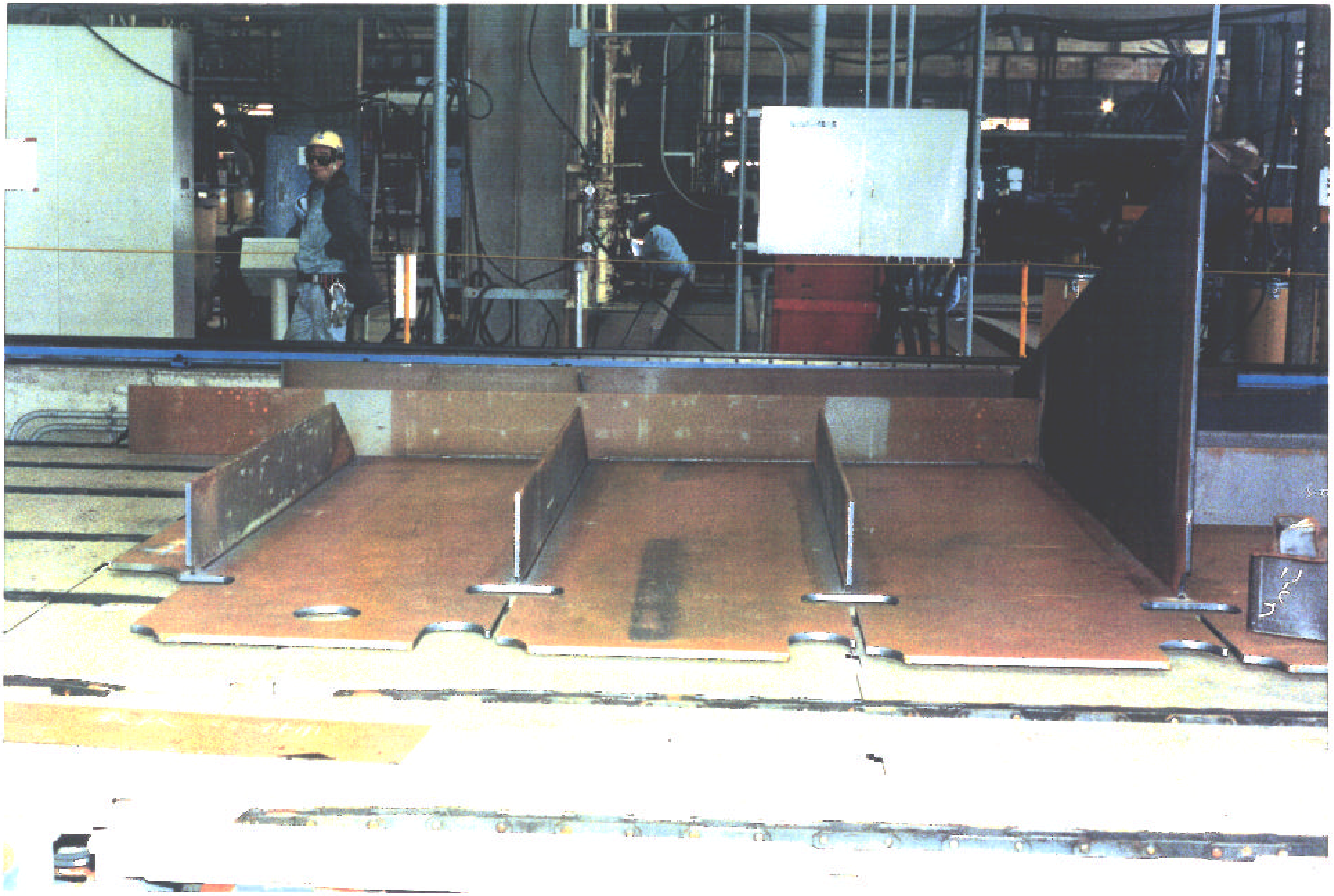
Stiffener Placement Robot at Sumitomo Yard



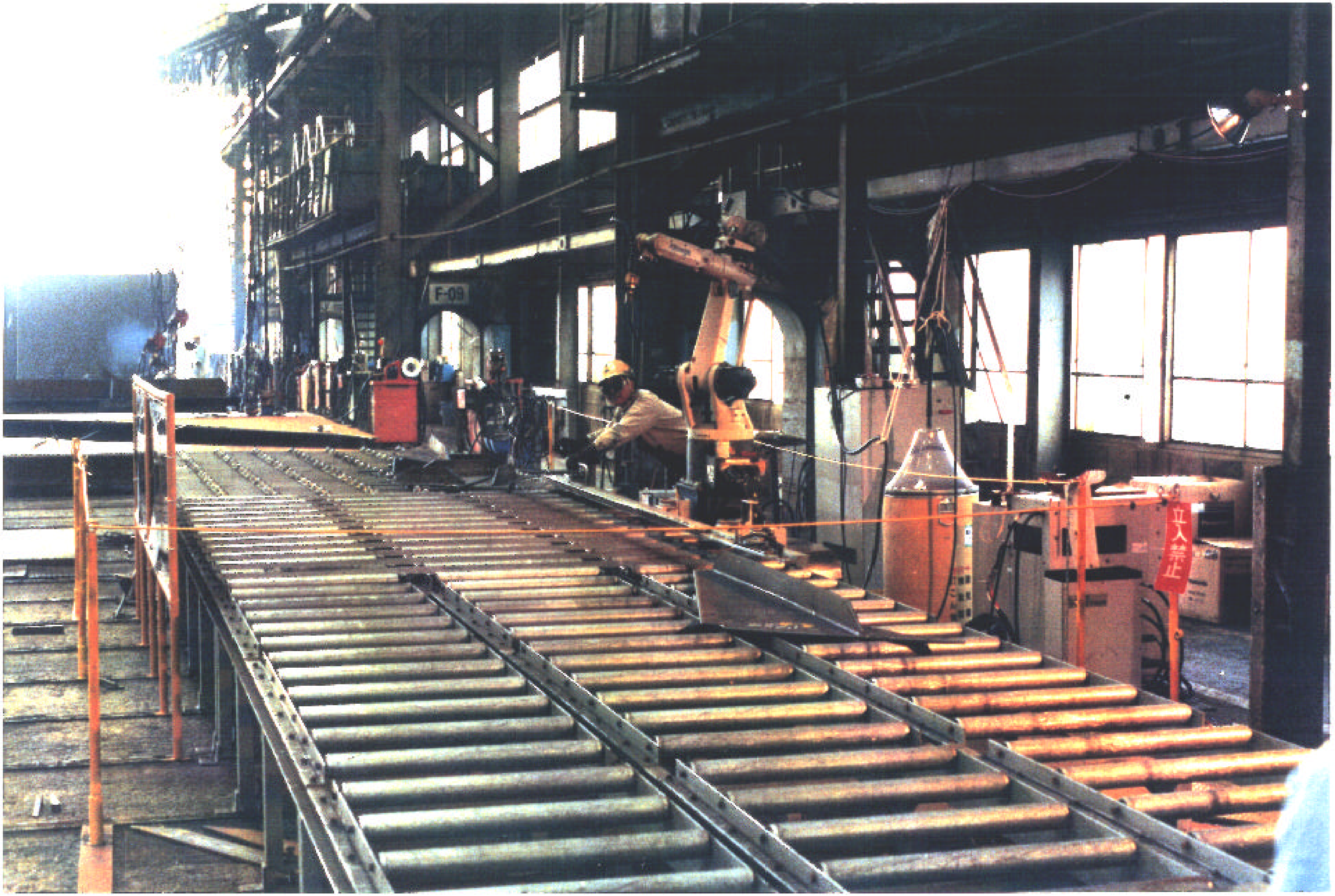
Stiffener Placement Operation



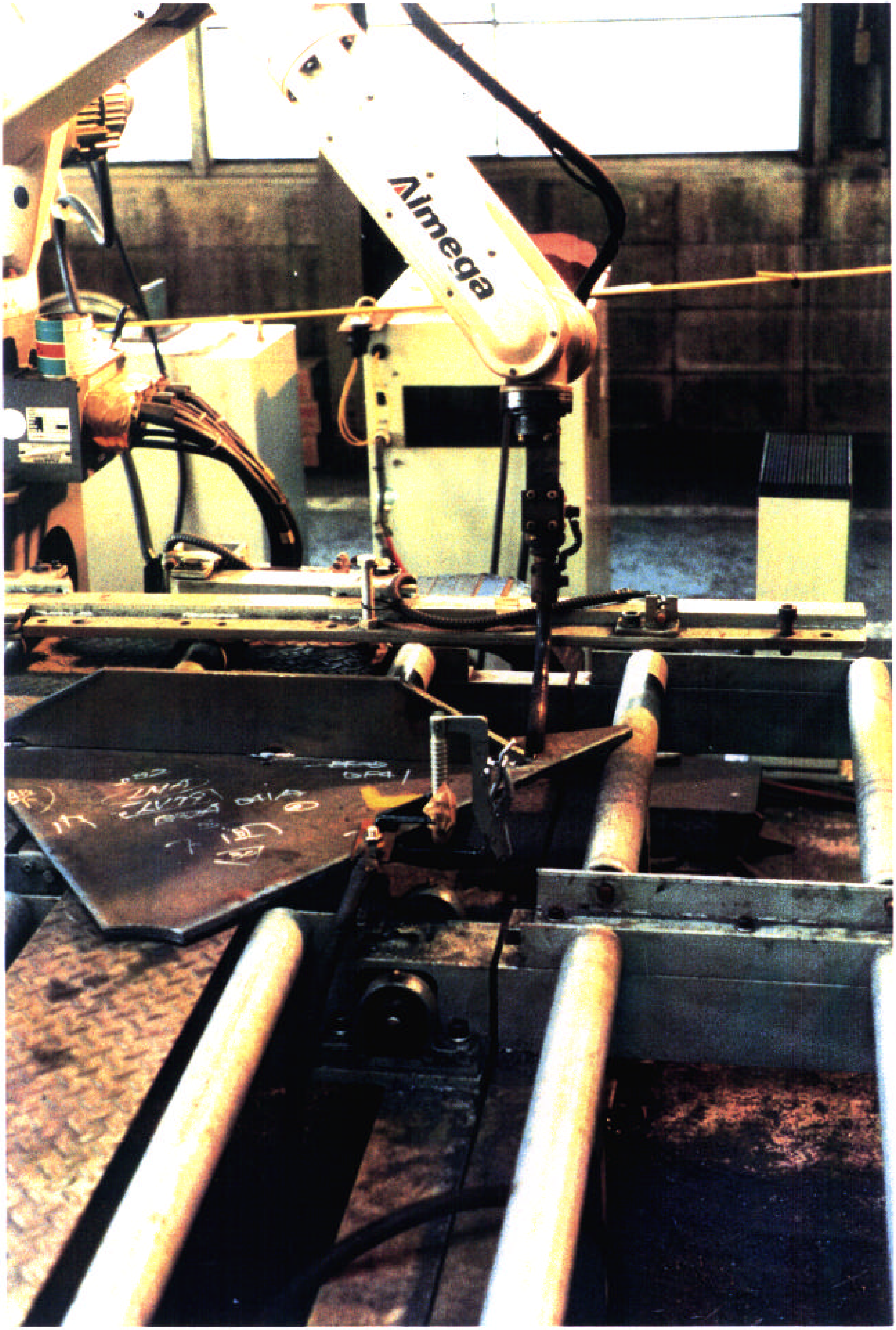
Sumitomo's Twin Torch Robot



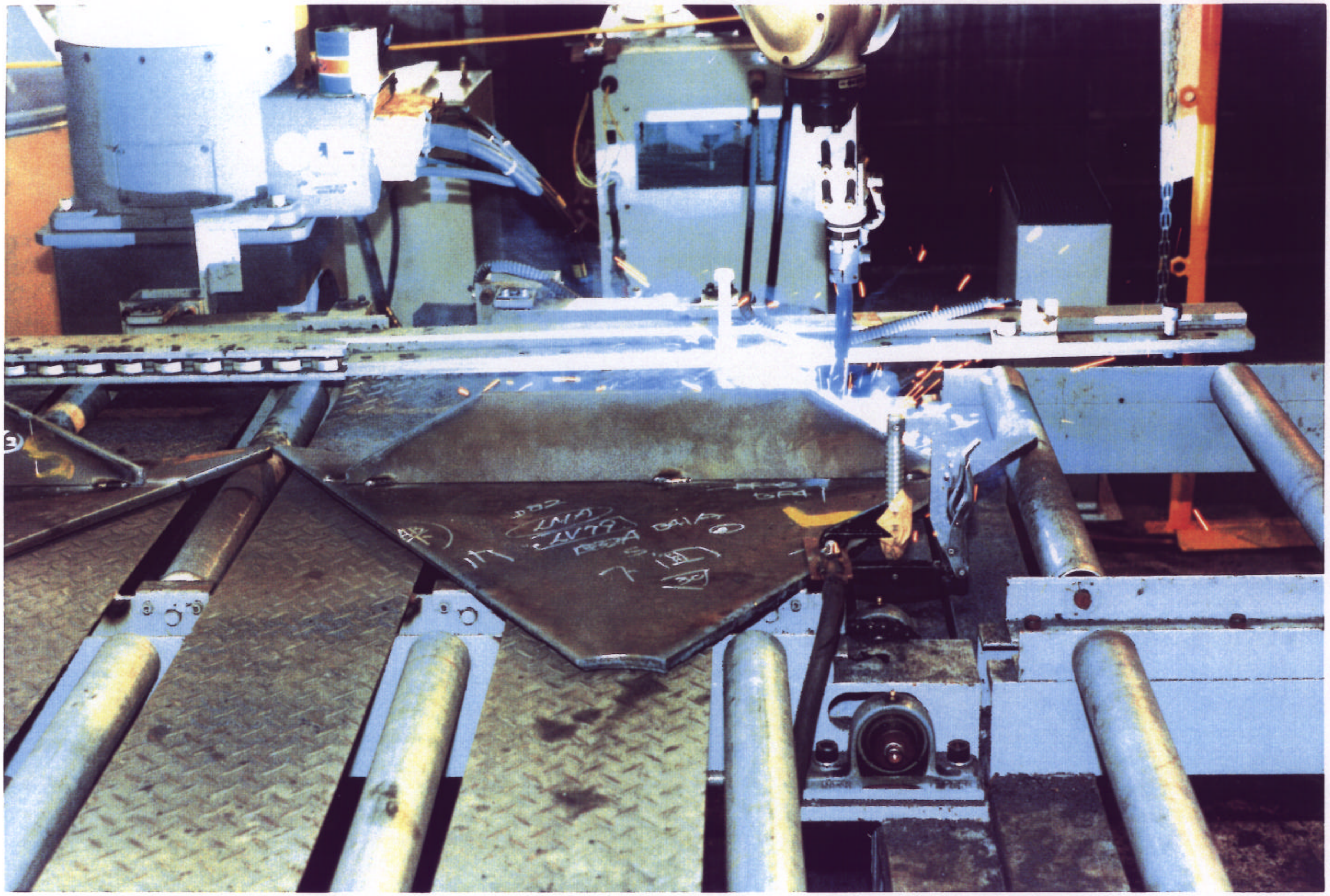
Typical Twin Torch Robot Application



Articulated Track Mounted Robot at Sumitomo Yard

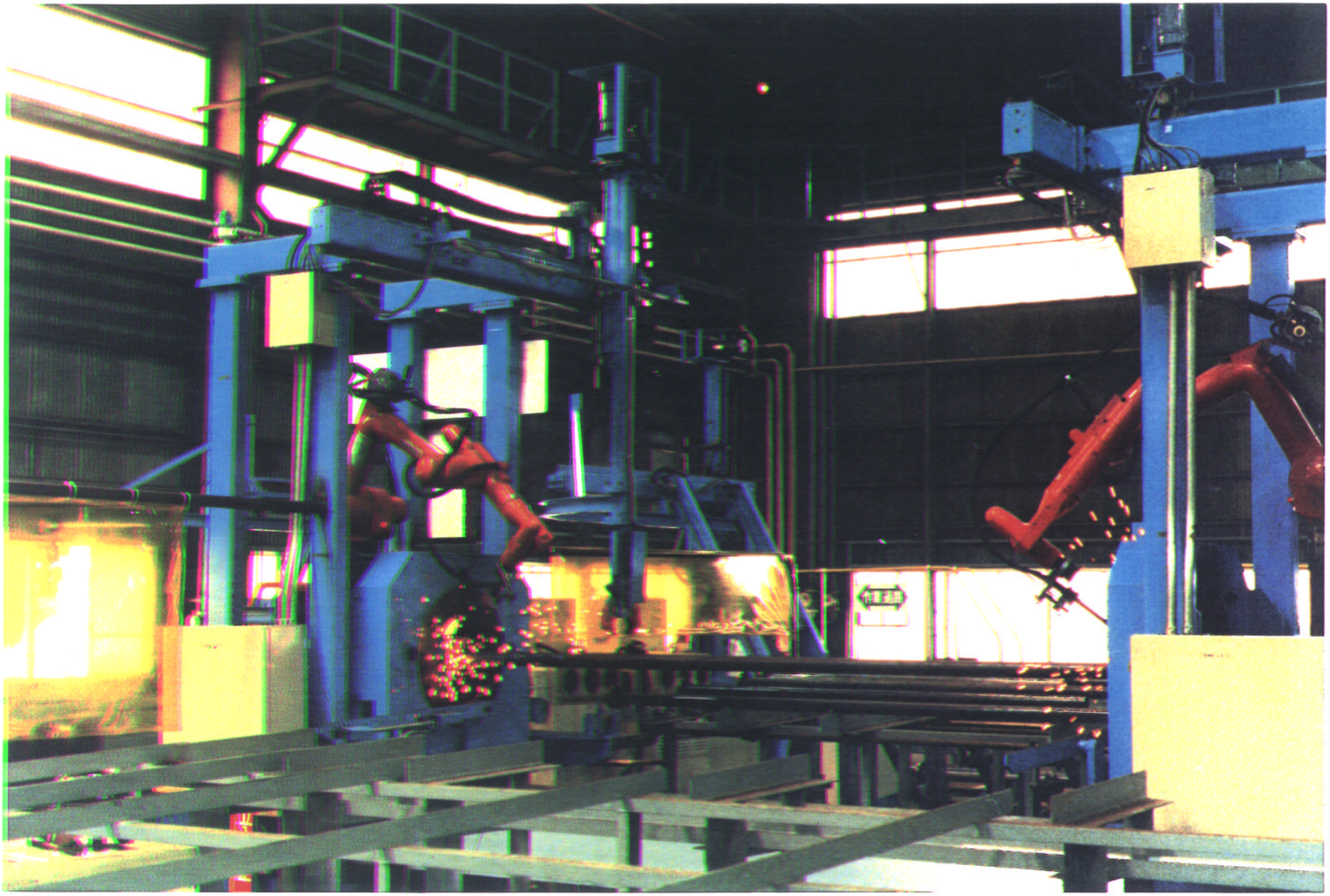


Touch Sensing in Operation

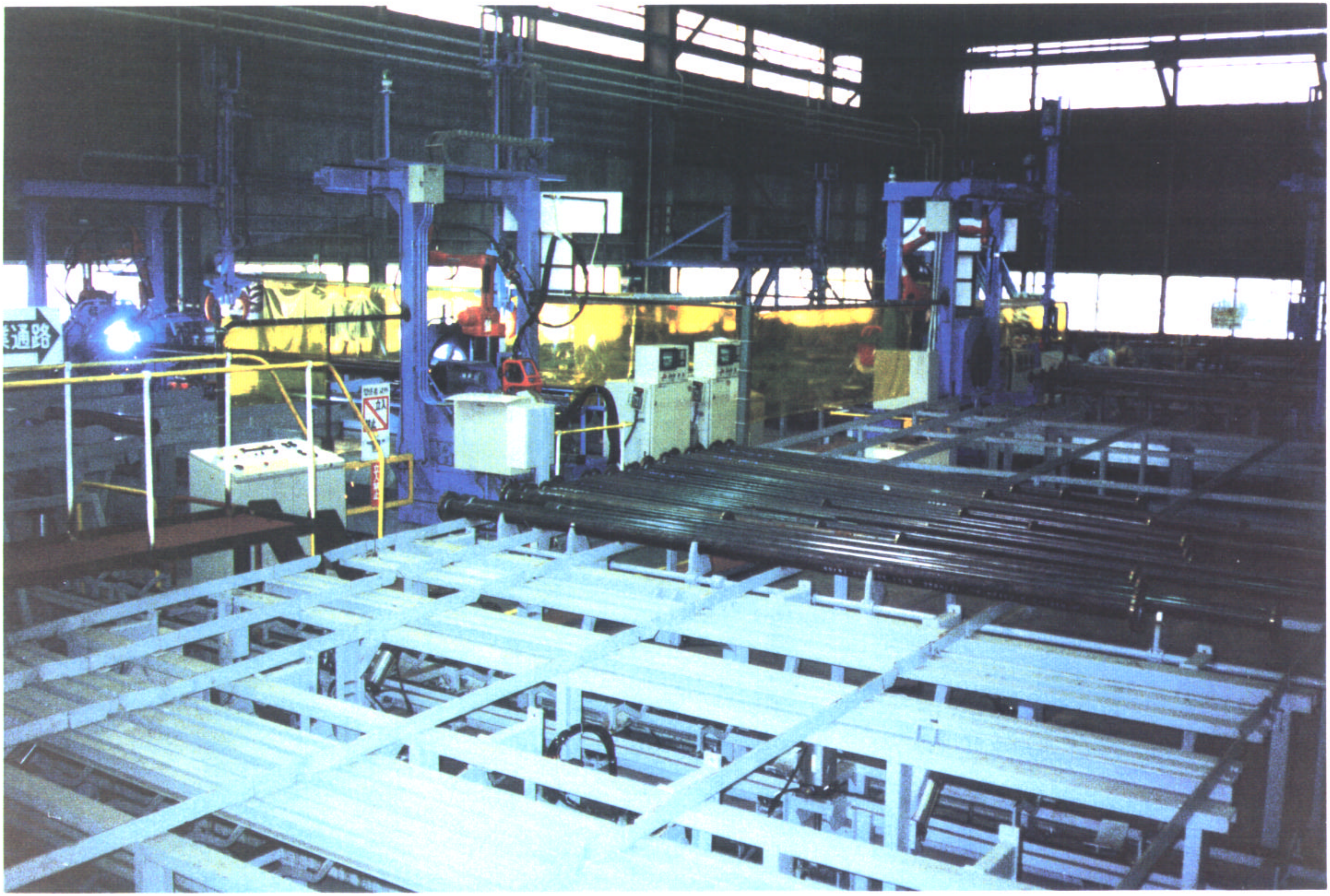


Fillet Welding of Stiffeners to Plate

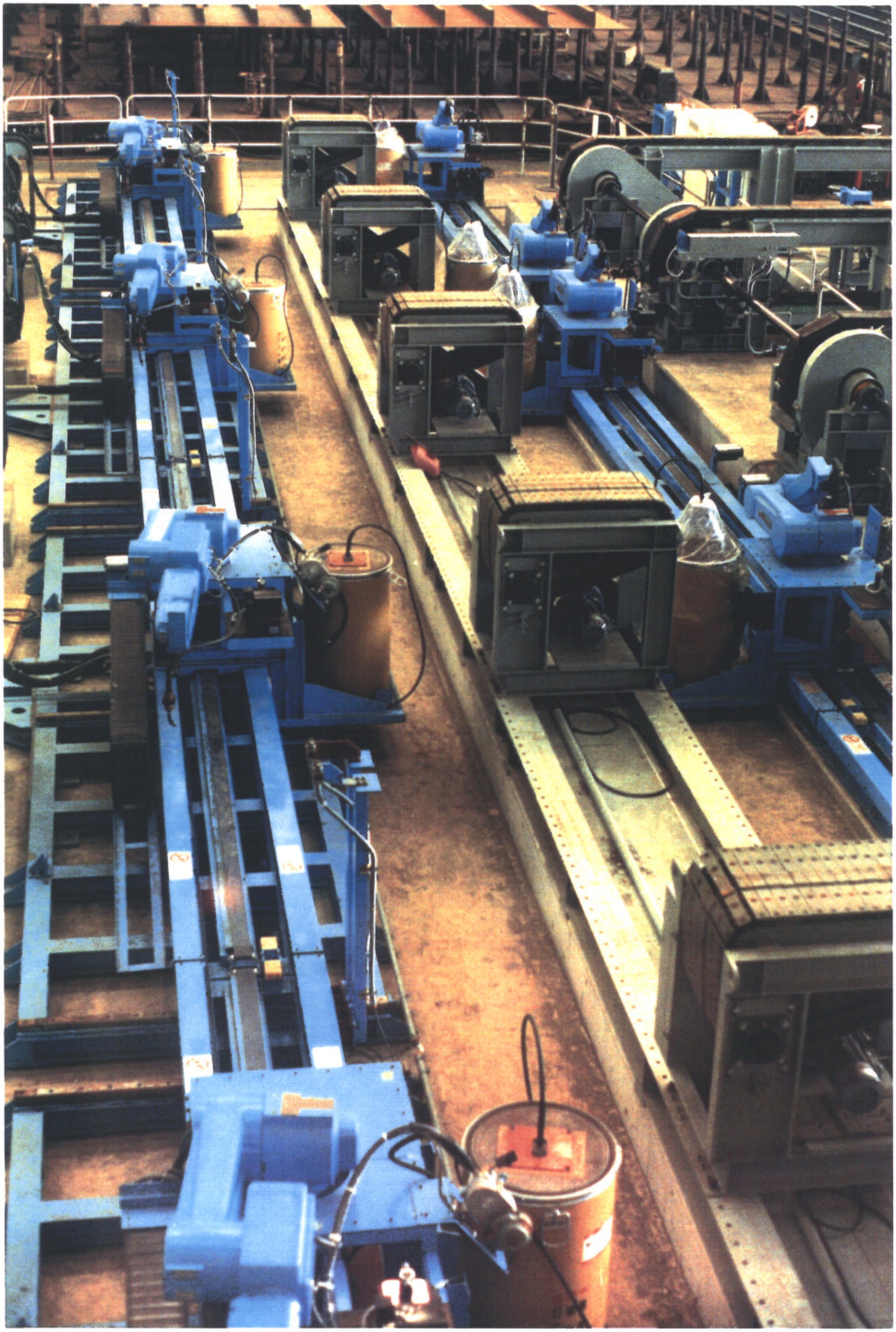
Typical Piece Parts for the Articulated Robot



Sumitomo's Robotic Pipe Welding Operation in Progress

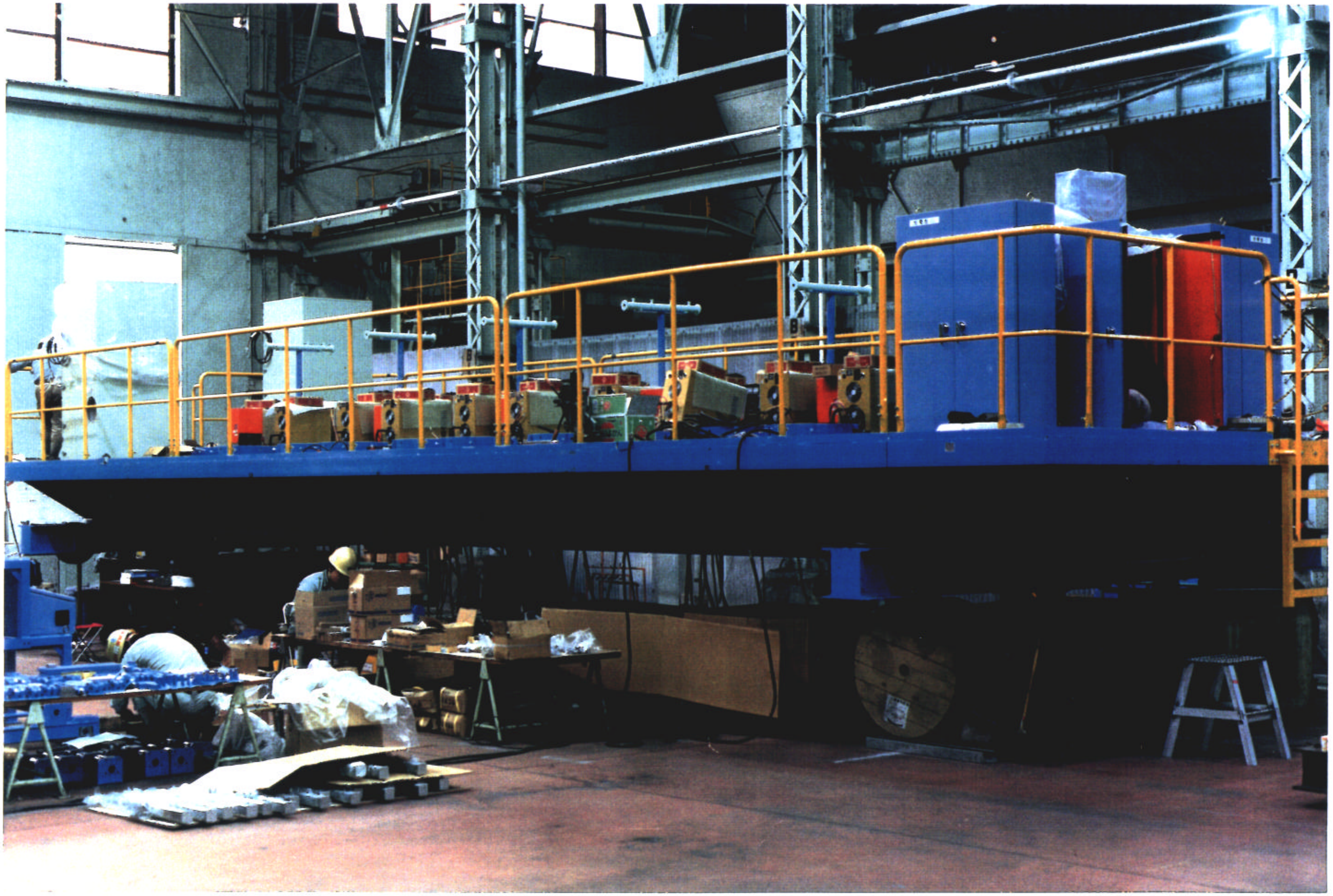


Small and Medium Pipe Welding Lines



Overhead View of Track Mounted Robots Used to
Weld the Undersides of Large Sub-assemblies

Side View of Track Mounted Robots



Bridge Crane Being Constructed to Support Four
WR-L50 Deep Reaching Robots for Ariake Works

ADDITIONAL COPIES OF THIS REPORT CAN BE OBTAINED BY CONTACTING:

JAMES ROGNESS
NSRP PROGRAM MANAGER - INDUSTRL4L PROCESSES
PETERSON BUILDERS, INC.
101 PENNSYLVANIA STREET
STURGEON BAY, WI 54235

PHONE: (414) 743-5574 EXT. 391
FAX (414) 743-3461